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THE EFFECT OF NONRESPONSE
on representativeness of Wilderness-Trail Register Information

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BY WILEY D. WENGER, JR., AND H. M. GREGERSEN

U.S. DEPARTMENT OF AGRICULTURE
PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION • FOREST SERVICE
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THE EFFECT OF NONRESPONSE *on representativeness of wilderness-trail register information*

By Wiley D. Wenger, Jr., and H. M. Gregersen

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INTRODUCTION

Reliable information about wilderness recreation use is essential to sound wilderness allocation and management. Such information may be obtained from a system of unmanned registration stations properly employed on wilderness trails.[1]

The specific objective for employing any particular system of stations might be one or both of the following: (1) to obtain a detailed estimate of amount and patterns of recreation use; (2) to obtain a description of the sociophysical characteristics of user types and the names and addresses of wilderness recreationists from which samples could be drawn for additional research.

Each of these objectives could be most easily met if all trail users registered and did so accurately. But, expectedly, some trail users do not register at all, and some register inaccurately. As a consequence, quantitative adjustments in "raw" registration data are necessary to obtain sound estimates and descriptions of actual recreation use and users. Also, an evaluation of bias, or distortion, inherent in the "raw" registration data is essential to deciding when and how that data can be used without adjustment to describe features of the entire population, such as length of stay or origin of visitors. It is also essential for sound extension of all research findings based on samples of names selected from registrations.

Quantitative estimation of actual use from registration data will be discussed in a subsequent report. This report evaluates the qualitative bias, or effect of nonresponse on the representativeness, of registration data obtained on two areas in Oregon. It examines the questions: How accurate a description of all recreationists is contained in the registrations of self-selected registrants? What social factors are associated with variation in response to registration stations?

Because the findings reported here are based on only two areas, they are not directly applicable to other areas. However, they do direct attention to some dimensions of wilderness-trail registration information likely to be biased on other areas. The report also suggests some other issues needing more attention by students of outdoor recreation, e.g., the adequacy of the "purpose of visit" concept.

The research methods are described first and are followed by the findings. A discussion of the findings and conclusions are then presented.

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[1] Wenger, Wiley D., Jr. A test of unmanned registration stations on wilderness trails: factors influencing effectiveness. U. S. Forest Serv. Res. Paper PNW-16, 48 pp., illus. 1964.

Research Methods

This evaluation of bias in raw registration data was part of a 2-year study testing the effectiveness of unmanned registration stations for obtaining wilderness-use information. The study was conducted during June to October of 1961 and July to September of 1962. The two study areas were the Three Sisters Wilderness and Mountain Lakes Wild Areas, located in the central and southern Oregon Cascades, respectively.

Registration stations each included (1) a sign to attract the trail user's attention and to elicit an appropriate registration response, (2) a box designed for storage and protection of forms and for use as a writing desk, and (3) accessory equipment, such as writing tools and a calendar. The 1962 stations had, in addition, a plastic-laminated map of local trails mounted above the registration box.

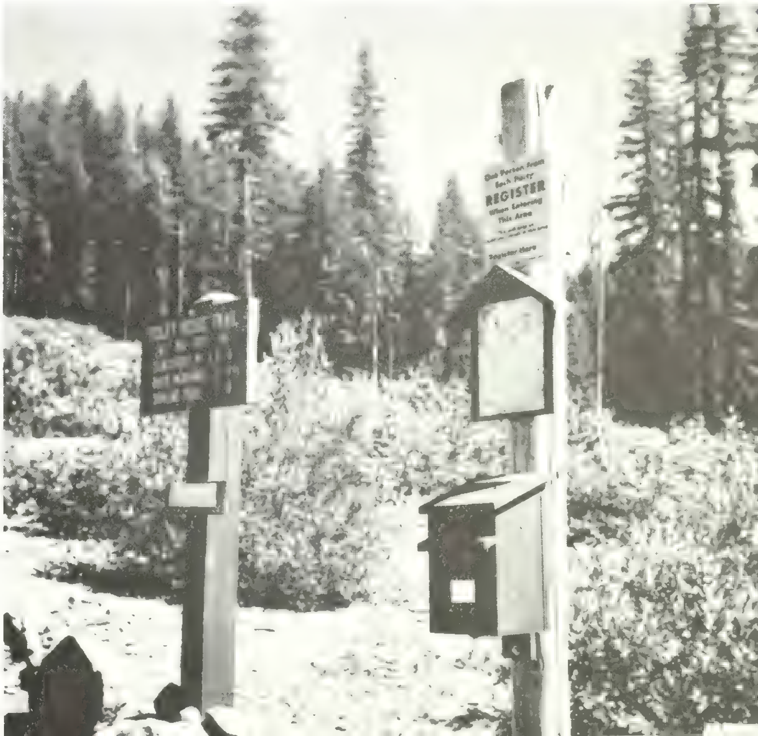
Stations were placed on all known access trails into each area (a total of 59 in 1962) at or near the point where the trails joined access roads (fig. 1). One person from each party was requested to register when both entering and leaving the area in 1961 but, in 1962, only when entering.

Data used to evaluate bias in registration data resulting from nonresponse or inaccurate response of user groups were obtained from interviews. According to a preplanned sampling plan, interviewers waited up survey trails beyond registration stations to interview parties after they had an opportunity to respond to a station. Interview periods on each survey trail were from 8 a.m. to 4 p.m. in 1961 and from 8 a.m. to 3 p.m. in 1962.

Data on each interviewed group were compared with registration data to determine if the group had registered. A total of 94 interviews with recreationists was obtained in 1961 and 146 in 1962.

Analyses for bias were based on groups and, more specifically, on the interviewee for each group. The interviewee was either a normal authority figure, e.g., father of a family group, or the informal leader of a more loosely organized group. Registered groups were compared with nonregistered groups on several variables for which adequate data were available. Chi-square analyses were made of the data, assuming groups to be independent. If sample differences on a variable could have occurred 5 or fewer times in 100 samples (0.05 significance level), the differences were considered significant in the population from which the sample was drawn.

Figure 1.—Unmanned registration stations were placed on all wilderness-access trails where they connected with access roads.



Samples of the registration forms and interview schedules used are shown in the appendix.

Additional details of research methodology are presented in a preceding report.[2]

Special terms used in this report are summarized below:

Area—one of the two study areas.

Block—a geographic subunit:

Block I—west side, Three Sisters Wilderness Area.

Block II—east side, Three Sisters Wilderness Area.

Block III—Mountain Lakes Wild Area.

Survey trail—one of the trails on which recreationists were interviewed: 18 in 1961, 10 in 1962.

Population—all recreation groups using the study areas in a specific year.

Sampling unit—one group of trail users.

Group; party—one or more persons traveling together and/or camping as a unit.

Group leader—a person who takes the initiative in registration or as interviewee, or both.

Class—category of user groups based on sociophysical characteristics of the groups:

Class	Mode of travel	Time in area	Origin of registrant
1	Hiking	Day or less	60 miles or more from area
2	''	'' '' ''	Less than 60 miles
3	''	Overnight or more	60 miles or more from area
4	''	'' ''	Less than 60 miles
5-8	Riding	--	--

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[2] See footnote 1.

Findings

Analyses were made for the following variables: (1) trails, (2) blocks, (3) days of week, (4) classes, (5) mode of travel, (6) size of party, (7) purpose of trip, (8) number of years' previous use, (9) number of times' previous use, (10) previous travel "this" year, (11) distance of residence community, (12) size of residence community, (13) reason for choosing areas to visit, (14) distance traveled in area, (15) length of stay, (16) membership of leader in an outdoor club, and (17) occupation of leader.

The responses to registration stations by groups are shown in table 1. A summary of the analyses is presented in table 2.

Table 1.—Responses of interviewed groups to registration stations, by several use variables

Year of data and variable	Registered groups	Non-registered groups	Total all groups	Percent regis-tered
1962 Trail No.:				
34	18	2	20	90.0
36	14	6	20	70.0
38	19	7	26	73.1
63	24	9	33	72.7
74	17	2	19	89.5
Total	92	26	118	78.0
1961 Block:				
I	36	9	45	80.0
II	27	16	43	62.8
Total	63	25	88	71.6
1962 Block:				
I	53	16	69	76.8
II	57	20	77	74.0
Total	110	36	146	75.3
1962 Days of week:				
Weekends and holidays	87	27	114	76.3
Weekdays	23	9	32	71.9
Total	110	36	146	75.3
1962 Class:				
1	36	8	44	81.8
2	45	15	60	75.0
3	10	3	13	76.9
4	15	3	18	83.3
5-8	4	7	11	36.4
Total	110	36	146	75.3
1961 Mode of travel:				
Hiking	60	15	75	80.0
Riding	8	11	19	42.1
Total	68	26	94	72.3
1962 Mode of travel:				
Hiking	106	29	135	78.5
Riding	4	7	11	36.4
Total	110	36	146	75.3
1961 Size of party:				
1 person	4	5	9	44.4
2 persons	22	7	29	75.9
3 "	12	8	20	60.0
4-5 "	18	5	23	78.3
6+ "	12	1	13	92.3
Total	68	26	94	72.3
1962 Size of party:				
1 person	3	7	10	30.0
2 persons	33	13	46	71.7
3 "	18	4	22	81.8
4-5 "	36	7	43	83.7
6+ "	20	5	25	80.0
Total	110	36	146	75.3
1962 Purpose of trip:				
General recreation	93	21	114	81.6
Fishing	8	15	23	34.8
Other specific	9	0	9	100.0
Total	110	36	146	75.3
1962 Number years' prior use:				
1-2	25	1	26	96.2
3-5	21	9	30	70.0
6-10	8	5	13	61.5
10+	15	7	22	68.2
Total	69	22	91	75.8
1962 Number times' prior use:				
1-2	20	4	24	83.3
3-10	23	3	26	88.5
10+	26	15	41	63.4
Total	69	22	91	75.8
1961 Prior travel "this" year:				
Yes	18	14	32	56.2
No	47	12	59	79.7
Total	65	26	91	71.4
1962 Prior travel "this year:				
Yes	33	16	49	67.3
No	77	20	97	79.4
Total	110	36	146	75.3

Table 1.—Responses of interviewed groups to registration stations, by several use variables—Continued

Year of data and variable	Registered groups	Non-registered groups	Total all groups	Percent registered
1961 Distance of residence:				
+ 60 miles	27	6	33	81.8
− 60 miles	41	20	61	67.2
Total	68	26	94	72.3
1962 Distance of residence:				
+ 60 miles	46	12	58	79.3
− 60 miles	64	24	88	72.7
Total	110	36	146	75.3
1961 Size of residence community:				
0-2,000	15	7	22	68.2
2,000-10,000	7	3	10	70.0
10,000-25,000	15	9	24	62.5
25,000+	31	7	38	81.6
Total	68	26	94	72.3
1962 Reason for choice of area:				
Friends	42	17	59	71.2
Close	12	5	17	70.6
Chance	21	1	22	95.4
Here before	31	11	42	73.8
Other	4	2	6	66.7
Total	110	36	146	75.3
1962 Distance went into area:				
− 1 mile	24	4	28	85.7
1-3 miles	37	14	51	72.5
4-10 "	43	16	59	72.9
10+ "	6	2	8	75.0
Total	110	36	146	75.3
1961 Length of stay:				
-1 day	50	17	67	74.6
1-3 days	14	6	20	70.0
4+ "	4	3	7	57.1
Total	68	26	94	72.3
1962 Length of stay:				
-1 day	84	29	113	74.3
1-3 days	19	6	25	76.0
4+ "	7	1	8	87.5
Total	110	36	146	75.3
1962 Member in outdoor club:				
Yes	19	5	24	79.1
No	91	31	122	74.6
Total	110	36	146	75.3
1962 Occupation of leader:				
White collar	82	23	105	78.1
Blue collar	22	11	33	66.7
Not employed	6	2	8	75.0
Total	110	36	146	75.3

Table 2.—Summary of chi-square analyses for bias in registration data

Variable	Year of data	Number of groups	Degrees of freedom	Chi-square at 0.05 level	Obtained chi-square
Trails (five heaviest used)	1962	118	4	9.49	4.79
Blocks	1961 1962	88 146	1 1	3.84 3.84	2.41 .04
Days of week	1962	146	1	3.84	.06
Classes	1962	146	4	9.49	10.65*
Mode of travel	1961 1962	94 146	1 1	3.84 3.84	9.07** 7.59*
Size of party	1961 1962	94 146	4 4	9.49 9.49	8.22 13.55**
Purpose of trip	1962	146	2	5.99	25.46***
Number of years' prior use	1962	91	3	7.82	8.65*
Number of times' prior use	1962	146	2	5.99	6.48*
Prior travel "this" year	1961 1962	91 146	1 1	3.84 3.84	4.48* 1.93
Distance of residence	1961 1962	94 146	3 1	3.84 3.84	1.61 .50
Size of residence community	1961	94	3	7.82	3.02
Reason for choice of area	1962	146	4	9.49	5.79
Distance went into area	1962	146	3	7.82	2.03
Length of stay	1961 1962	94 146	2 2	5.99 5.99	1.10 .73
Membership of leader in outdoor club	1962	146	1	3.84	.05
Occupation of leader	1962	146	2	5.99	1.81

* Significant at or beyond the 0.05 level.
** Significant at or beyond the 0.01 level.
*** Significant at or beyond the 0.001 level.

Discussion of the Analyses

From the analyses it appears that the registration data may be distorted or incorporate bias on several dimensions. These variables are classes, mode of travel, size of party, purpose of trip, and frequency of prior use of the area. For the other variables, registration data seems appropriate as a basis for generalizations about all trail users of the study areas. Further explanation and qualification of these broad interpretations follow.

Trails and Blocks

Only the five heaviest used trails were included in the analyses; less heavily used trails were excluded because the small cell frequencies violated the assumptions of the chi-square test. The trails analyzed did not include any trails with predominant horseback use.

The variation occurring for the trails analyzed could have occurred by chance more than 5 in 100 times. Consequently, it may be concluded that trails with roughly similar types of use will receive roughly similar registration responses.

When use characteristics for trails are sharply dissimilar, especially on variables known to be associated with response bias, a closer look at trail-associated bias is necessary. For example, the same registration-data expansion factors should never be blindly applied across trails without first determining if the rider-hiker mix is significantly different for some of the trails.

The two blocks compared in the analysis were contiguous but distinctly different geographically. Differences in use characteristics could be expected for each block. Whatever differences occurred did not influence the registration response, which showed only chance variation. This finding makes it credible that the high quality of response obtained on this area might also be found on other wilderness-type areas.

Block III, the Mountain Lakes Wild Area, could not be included in the analysis because of insufficient data.

Days of Week

The response of groups to registration stations did not vary between weekends (and holidays) and weekdays. Factors directly associated with different days of the week include principally a greater tendency to bunch up at stations on weekends and holidays. Apparently, this factor does not exert an important influence on overall response.

Classes and Mode of Travel

The classes compared here are the classes defined on page 4. Although a significant difference is apparent across classes, this conclusion must be qualified sharply. Another chi-square analysis comparing only the hiking classes showed differences between these classes to be nonsignificant (chi-square: 1.02, 3 d.f., $0.80 > P > 0.70$). But the analysis on the mode of travel variable, a confounded variable in the class analysis, showed that response differences for mode of travel were significant. Consequently, apparent response differences between classes are really attributable only to the differences between groups using different modes of travel.

Hikers respond at registration stations far more adequately than riders, as one might expect. This difference is more dramatic when it is realized that it was anticipated, and deliberate attempts were made to accommodate stations to the convenience of riders. The failure of these attempts makes it seem clear that social, not physical, factors predominantly underlie the difference. Registration data disproportionately undersample riders and will need accommodation for this bias.

Size of Party

Parties with only one person are not registered as frequently as larger parties. The difference in response was most apparent in the 1962 data; however, the same difference is suggested by the 1961 data.

What factors are associated with this lower response rate for one-person parties? Wording of the sign at the registration station is one factor that may have influenced the difference. Did the sign adequately convey to one-person parties that they were also included in the request for "parties" to register? The 1962 sign was less ambiguous about who should register; however, it was most apparent in the 1962 analysis that one-person parties did not register. A clue is thereby gained that sign wording was not significantly associated with the registration failures.

Size of party is associated with purpose of trip; six of the seven one-person nonregistrant parties in 1962 were fishermen. In response to this clue, all 1962 interviewees were classified by size of party and purpose of trip, and a chi-square analysis was made. Table 3 presents the data.

Table 3.—Purpose of trip for 1962 interview groups of different sizes

Size of party	Primary purpose		Total
	Fishing	Not fishing	
1	7	3	10
2 or more	16	120	136
Total	23	123	146

With a chi-square of 19.62, the obtained differences would have occurred by chance only once or less in 1,000 times. Apparently, one-person parties are much more likely to be primarily classified as fishing than are larger parties. However, as will be seen in the next section, larger groups were less likely to be classified with a specific single purpose such as fishing. Nonetheless, it is apparent that one-person parties tend to be fishermen, and, as discussed later, fishermen do not register as well as others.

Other factors may also be involved in the obviously already complicated interaction. For example, it might be expected that single persons would be less likely to register because they are not exposed to the immediate constraints of socially appropriate action present in the company of others.

What effect does this response bias have on data averages, especially average number of persons per group? As seen in table 4, no effects are apparent. Therefore, a quantitative correction seems unnecessary.

Table 4.—Actual and registered average number of persons per group

Category	1961	1962
Actual average number of persons per group	3.915	3.877
Registered average number of persons per group	3.440	3.782

Purpose of Trip

Only recreationists were included in the evaluation of registration stations; groups with an administrative or commercial interest were excluded, e.g., Forest Service crews, mineral prospectors, etc. Recreation groups were broadly classified according to the principal type of recreation activity pursued.

For most trail users there is no one specific purpose of their trip. An individual's motives are usually compound—he may wish to see something new or beautiful, exercise his legs, pacify the family, catch fish, collect photographic trophies, have a good social time, etc., and rarely will he be primarily concerned with only one of these motives. The mixture will vary, of course, with different persons. A group, then, would usually be on the trail with many purposes, and forced-choice classification into narrow categories is meaningless. Consequently, recreation groups were classified as follows:

General type. Includes all composite-type recreation activities, e.g., "going to lake," camping, hiking, sightseeing. But if qualifying evidence was present indicating that the group had a restricted interest in a recreation form, the group was classified under a specific type, e.g., the Trails Club hiking the Skyline Trail.

Specific type, fishing.

Specific type, hunting.

Specific type, other. For example, mountain climbing, rock collecting, botanical study, etc.

Appropriately, most groups fell into the "general type" category. Conversely, few groups fitted the "fishing" category because fishing is usually an individual sport. Although fishermen might have been present in a group, the presence of nonfishermen resulted in a "general type" classification. The nature of other "specific type" categories better accommodated relatively larger groups than the "fishing" category.

"Purpose of trip" was associated with a significant difference in registration response of groups. "Fishing" groups were not registered as often as other groups. In the discussion on size of party, it was noted that the "fishing" groups did, indeed, tend to be one-person groups. And one-person groups also made a poor showing at registration stations. The relationship is not fully understandable from the data but indicates that (1) additional associated variables should be sought and (2) the concept of "purpose of trip" needs further refinement.

Although sufficient quantitative data were not gathered during the hunting season to analyze hunters' responses, observations were made informally. It was overwhelmingly apparent that elk hunters, as a subclass, ignored the stations.[3] The response of deer hunters was less obvious and needs further study.

In summary, purpose of trip was associated with response variation at registration stations. Attention should be given this variable in any consideration of bias in registration data, especially in the light of other evidence that social characteristics are differentially associated with different outdoor recreation activities.

Frequency of Use

Prior use of the study area by registrants seems associated with response bias. Supporting evidence comes from the analyses of number of years and times of previous use of the area.

In 1961, interviewees who had already visited the area that year were not registered as often as interviewees making their first 1961 visit. This could indicate a generally poorer response for persons after their first exposure to a station. However, in the 1962 data the relationship was not confirmed. The registration task was somewhat more burdensome in the 1961 study and may be the source of the 1961 difference, or the manipulation of station design in 1961[4] may have had some influence.

When entire past use was considered, no significant difference occurred between first-time users and users who had visited the area previously. But for repeat users, number of years and times of previous travel were associated with response bias. More users registered who had visited the area only 1 or 2 previous years and from 1 to 10 previous times.

It could be that first-time users would include a substantial number of casual persons who might be inclined to ignore the registration stations. Those who returned for a second trip would, presumably, be more interested in the area and amenable to registering if that seemed to them supportive of the area management. However, the oldtimers, long committed to use of the area, thoroughly familiar with the terrain, confident of their abilities, and with a feeling of vested interest, could be expected to be less responsive to the stations. Although other theories could be entertained, the data seem highly supportive of this one.

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[3] Hunter vandalism was not an apparent problem.

[4] See footnote 1.

The implications of this response bias need consideration when interpretation is made of registration data.

Residence Community

Interviewees were categorized on the basis of distance of their homes from the centers of study areas. Responses of those who lived more than 60 miles from the area visited were compared with those who lived closer to the area. No significant response difference between these groups was apparent. Sizes of the residence communities were then examined. Again no significant response difference was apparent. Groups seem to register about as well whether from the local area or further away, from a rural community or large city.

Reason for Choosing Area

Interviewees in 1962 were asked how they happened to pick this particular area for their trip. Responses were grouped into the following categories: "friends told us about it," "it was close to home," "found it by chance," "was here before and liked it," "other." Groups in each category registered about equally well, that is, differences could have occurred through random sampling errors. Therefore, the question revealed no response bias.

Distance Traveled into the Area, Length of Stay

Is registration response associated with a group's penetration into the area? Groups were categorized on the basis of how far interviewees said they were going or had gone, objective validity of their estimates notwithstanding. No significant differences in registration responses between categories were discovered. Even parties going less than a mile registered as well as, perhaps slightly better than, parties traveling further. How long groups stayed in the area before returning to a road also was not associated with registration response.

Membership in Outdoor Clubs

Are persons who have indicated commitment to the out-of-doors by membership in an outdoor club more likely to register than others? Apparently not; differences in response were not significant.

Occupation

Occupations of interviewees were used as a crude means of determining social status. Occupations were grouped as follows:

White collar—nonmanual types of jobs
Blue collar—manual jobs
Unemployed—retired persons, housewives, unemployed

Occupations so categorized were not significantly associated with response bias.

Conclusions

For some purposes, it is necessary or desirable to use registration data "raw." Examples of such uses would be estimation of length of stay of visitors or sampling for further research studies by using names and addresses of registrants. For these purposes, it is essential to know of bias inherent in the data because of differential response at various places and times or by various classes of users. Knowing what bias is inherent in the raw registration data, we might make suitable adjustments or modify the interpretations of all findings that flow from the raw data.

From the preceding analyses, we conclude that raw registration data is not an unbiased record of all characteristics of all trail users on an area. Some types of persons distort the data on relevant variables by their tendency to avoid registration. Certain variables likely to be distorted have been identified, and possible reasons for distortion on the variables have been offered as a first step in handling the biases.

From the survey data, response biases were discovered to be associated with mode of travel, purpose of trip, size of party, and frequency of previous use. Riders, fishing and elk hunting parties, and single-person parties tended to register less frequently than others; therefore, the registration data underrepresented these user groups. Also underrepresented or underreported by the registration data were persons who had used the area more than 10 times or 3 years.

In some important areas of bias, especially "purpose of trip," the concepts underlying the variable are obscure or poorly conceived. Special attention needs to be concentrated on refinement of the underlying concepts if the data are to be useful on the variables.

The variables studied here were derived primarily from the problems of backcountry managers, and a superficial understanding of bias was afforded. But the problems are interrelated with the social backgrounds and other characteristics of the different classes of wilderness users. Research aimed directly at these social characteristics is also needed if they are to be reflected in management practices aimed at accommodating the specific needs of each user class.

An important implication of the study is that different types of persons and groups use the study areas—we found no homogeneous wilderness-user type. Those different types of persons respond to registration stations in different ways, as we might expect that they respond in different ways to other features of the environment, natural or imposed. Managers might better recognize these differing responses, link them to the deeper, underlying social variables and needs, and retranslate this increased knowledge of users and the benefits of use into management action that is responsive to the diverse needs of diverse wilderness-user groups.

Registration stations are highly effective in obtaining the needed basic information useful as "first aid" for management problems and for further research. But the effects of nonresponse must be fully considered, and appropriate modification in interpretations must be made of findings stemming from registration data used raw.

APPENDIX

Registration Forms and Interview Schedules

1961

REGISTRATION BOOK

Please answer all questions. One person only register for each group.

Name of group leader ____________________

Street or Box ____________________

City and State ____________________

Date ________________ Time _____ ☐ a.m. ☐ p.m.

The number of persons in this group
16 years of age and older _____
younger than 16 years _____

The purpose of this trip is
(check one) ☐ recreation
☐ Forest Service work
☐ other work ________
(what?)

(check one) ☐ We are entering area
☐ We are leaving area

(check one) ☐ We are walking
☐ We are riding horses
☐ Other __________
(what?)

(check one) ☐ We are backpacking
☐ We are stock packing
☐ We have no packs

We're going or have been in the area
(check one) ☐ less than 1 mile
☐ 1 mile to 15 miles
☐ more than 15 miles

Please answer all questions. One person only register for each group.

Name of group leader ____________________

Street or Box ____________________

City and State ____________________

Date ________________ Time _____ ☐ a.m. ☐ p.m.

The number of persons in this group
16 years of age and older _____
younger than 16 years _____

The purpose of this trip is
(check one) ☐ recreation
☐ Forest Service work
☐ other work ________
(what?)

(check one) ☐ We are entering area
☐ We are leaving area

(check one) ☐ We are walking
☐ We are riding horses
☐ Other __________
(what?)

(check one) ☐ We are backpacking
☐ We are stock packing
☐ We have no packs

We're going or have been in the area
(check one) ☐ less than 1 mile
☐ 1 mile to 15 miles
☐ more than 15 miles

Please answer all questions. One person only register for each group.

Name of group leader ____________________

Street or Box ____________________

City and State ____________________

Date ________________ Time _____ ☐ a.m. ☐ p.m.

The number of persons in this group
16 years of age and older _____
younger than 16 years _____

The purpose of this trip is
(check one) ☐ recreation
☐ Forest Service work
☐ other work ________
(what?)

(check one) ☐ We are entering area
☐ We are leaving area

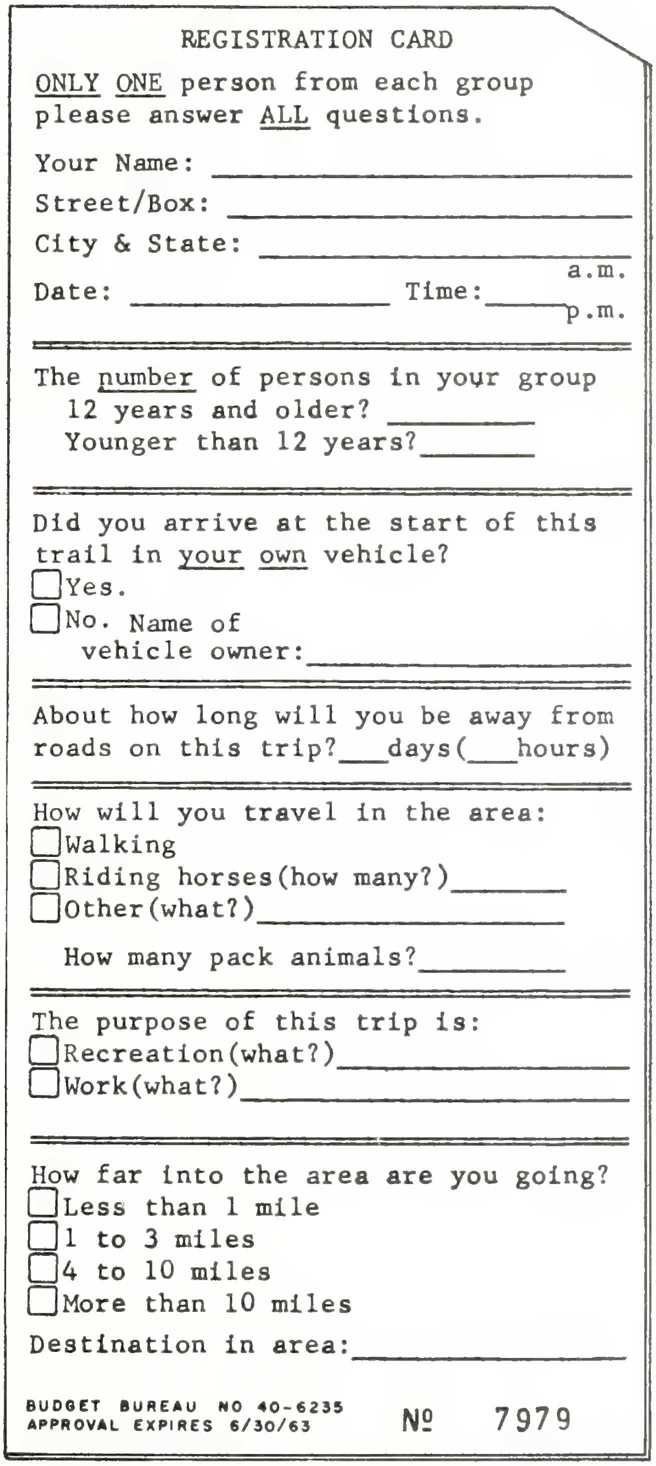
(check one) ☐ We are walking
☐ We are riding horses
☐ Other __________
(what?)

(check one) ☐ We are backpacking
☐ We are stock packing
☐ We have no packs

We're going or have been in the area
(check one) ☐ less than 1 mile
☐ 1 mile to 15 miles
☐ more than 15 miles

BUDGET BUREAU NO 40-6132
APPROVAL EXPIRES 6/30/62

1962 Registration Card



REGISTRATION CARD

ONLY ONE person from each group please answer ALL questions.

Your Name: ____________________

Street/Box: ____________________

City & State: ____________________

Date: ______________ Time: ______ a.m. p.m.

The number of persons in your group

12 years and older? ________

Younger than 12 years? ________

Did you arrive at the start of this trail in your own vehicle?

☐ Yes.

☐ No. Name of vehicle owner: ____________________

About how long will you be away from roads on this trip? ___ days (___ hours)

How will you travel in the area:

☐ Walking

☐ Riding horses (how many?) ________

☐ Other (what?) ____________________

How many pack animals? ________

The purpose of this trip is:

☐ Recreation (what?) ____________________

☐ Work (what?) ____________________

How far into the area are you going?

☐ Less than 1 mile

☐ 1 to 3 miles

☐ 4 to 10 miles

☐ More than 10 miles

Destination in area: ____________________

BUDGET BUREAU NO 40-6235
APPROVAL EXPIRES 6/30/63

№ 7979

Budget Bureau No. 40-6131
Approval expires 6/30/62

1961
FIELD INTERVIEW QUESTIONNAIRE

Wilderness-Use Study

Instructions to interviewer:

1. This form is to be filled out by you. Do not give it to the interviewee to fill out by himself. However, if an interviewee wishes to look at the form, it is permissible for him to do so.
2. Read to the interviewee only the capitalized wording.
3. Count for yourself the number of persons and number of pack and saddle stock.
4. Read the detailed instructions for interviewers.

HELLO. I'M MAKING A SURVEY OF TRAIL USERS. WHICH PERSON IS THE GROUP LEADER? (Go to the designated person).

HELLO. I'M ___(your name)___ . I'M WITH THE U.S. FOREST SERVICE. WE'RE MAKING A ROUTINE SURVEY OF TRAIL USERS. INFORMATION YOU GIVE ME WILL HELP THE FOREST SERVICE MEET THE NEED FOR TRAILS AND OTHER FACILITIES IN THIS AREA.

WHERE DO YOU LIVE? ____________________________
(City and State)

HOW DO YOU SPELL YOUR NAME? ____________________________

WHAT IS YOUR ADDRESS IN (name of city)? ____________________________

HOW LONG DO YOU EXPECT TO STAY IN THIS AREA BEFORE ARRIVING BACK AT A ROAD?

☐ less than 1 day
☐ overnight to 3 days
☐ 4 to 7 days
☐ 8 days to 2 weeks
☐ over 2 weeks

HAVE YOU TRAVELED TRAILS IN THIS AREA BEFORE? ☐ no
☐ yes
(if "yes", ask) THIS YEAR? ☐ no
☐ yes

THANK YOU VERY MUCH FOR YOUR HELP. HAVE A GOOD TRIP!

Total number of persons in group? ☐

Total number of pack and saddle stock? ☐

(check one) ☐ walking
☐ riding horses
☐ other __________
(specify)

Interview date ________________ Time ____ ☐ a.m. ☐ p.m.

Trail No. ____________. Interviewer's initials ______.

Budget Bur.No. 40-6134A
Approval expires 6/30/63

1962

FIELD INTERVIEW QUESTIONNAIRE
(Revised Form)

Wilderness-use Study Form A (Entering)

INTERVIEWER: Only you are to fill this out! Read detailed instructions before beginning. Questions 1-11 refer to interviewee only.

HELLO. I'M MAKING A SURVEY OF TRAIL USERS. WHICH PERSON IS THE GROUP LEADER? (Go to designated person)

I'M (interviewer's name). I'M WITH THE U.S. FOREST SERVICE. I'M GATHERING INFORMATION THAT WILL HELP THE FOREST SERVICE MEET YOUR CHANGING NEEDS FOR TRAILS AND OTHER FACILITIES IN THE AREA.

1. (A) HAVE YOU EVER TRAVELLED TRAILS IN THIS AREA BEFORE?
☐ Yes (if yes, ask): ☐ No (if no, skip to question 3)

(B) EARLIER THIS YEAR?
☐ Yes (if yes, ask): ☐ No (if no, skip to question 2)

(C) WHICH TRAILS WERE YOU ON THIS YEAR? ______

2. ABOUT HOW OFTEN HAVE YOU USED TRAILS IN THIS AREA PREVIOUS TO THIS YEAR? (Probe for both years and times)

Years:	Times:
☐ 1 year	☐ 1 time
☐ 2 years	☐ 2 times
☐ 3-5 years	☐ 3-5 times
☐ 6-10 years	☐ 6-10 times
☐ More than 10 years	☐ More than 10 times

3. HOW DID YOU HAPPEN TO PICK THIS PARTICULAR AREA FOR YOUR TRIP RATHER THAN SOME OTHER?
☐ Friends told us about it
☐ Close to home
☐ Found it by chance
☐ Been here before and liked it
☐ Other: ______

4. (A) ARE YOU A MEMBER OF AN OUTDOOR CLUB?
☐ Yes (if yes, ask): ☐ No (if no, skip to question 5)

(B) WHICH ONE? ______

(C) IS THIS TRIP SPONSORED BY YOUR CLUB?
☐ Yes ☐ No

5. HOW LONG DO YOU PLAN TO STAY IN THE AREA BEFORE GETTING BACK TO THE ROAD?
☐ Less than 1 day
☐ Overnight to 3 days
☐ 4-7 days
☐ 8 days to 2 weeks
☐ Over 2 weeks

FIELD INTERVIEW QUESTIONNAIRE--Form A--page 2.

6. HOW MANY MILES DO YOU PLAN TO GO INTO THE AREA THIS TIME?
☐Less than 1 mile
☐1 mile to 3 miles
☐4-10 miles
☐More than 10 miles

7. WHERE IN THE AREA DO YOU PLAN TO GO? ____________________

8. WHERE IS YOUR HOME? (city & state) ____________________

9. WHAT IS YOUR ADDRESS IN (name of city)? ____________________

10. HOW DO YOU SPELL YOUR NAME? ____________________

11. WHAT IS YOUR OCCUPATION? ____________________

12. (A) BY WHAT MEANS OF TRAVEL DID YOU ARRIVE AT THE BEGINNING OF THIS TRAIL?
☐Motor vehicle
(if motor vehicle, ask):
☐Other(what?):____________________
(skip to question 13) ____

(B) DID YOUR PARTY ARRIVE IN MORE THAN ONE VEHICLE?
☐Yes
(if yes, ask):
☐No
(if no, ask):

(C) (1) WHAT ARE THE NAMES OF THE OWNERS?
☐Registrant owns one
☐Other owners(names):
____
____

(2) DOES THE VEHICLE BELONG TO YOU?
☐No
☐Yes
(skip to 12)

(3) WHAT IS THE OWNER'S NAME?
____

13. WHAT IS THE MAJOR PURPOSE OF THIS TRIP?
☐Recreation(what?):________________ ☐Work(what?): ____________

14. DO YOU HAVE ANY FURTHER COMMENTS ABOUT THIS AREA? (Write key words to remarks at time of interview. Detail remarks after interview).

THANK YOU FOR YOUR HELP. HAVE A GOOD TRIP.

15.☐Total number of persons in group
16.☐Total number of pack stock
17.☐Total number of riding stock

18. Recreation equipment visible:________
____

19. Age and sex distribution of group:
____females older than 12
____females younger than 12
____males older than 12
____males younger than 12

Interview date:____________ Interview time:__________ a.m. p.m. Trail Number:_____

Trail Name: ____________________ Interviewer's initials:_____

Interviewer: Make additional comments on back!

Budget Bur.No. 40-6134B
Approval expires 6/30/63

1962

FIELD INTERVIEW QUESTIONNAIRE
(Revised Form)

Wilderness-use Study Form B (Leaving)

INTERVIEWER: Only you are to fill this out! Read detailed instructions before beginning. Questions 1-11 refer to interviewee only.

HELLO. I'M MAKING A SURVEY OF TRAIL USERS. WHICH PERSON IS THE GROUP LEADER? (Go to designated person)

I'M (interviewer's name) . I'M WITH THE U.S. FOREST SERVICE. I'M GATHERING INFORMATION THAT WILL HELP THE FOREST SERVICE MEET YOUR CHANGING NEEDS FOR TRAILS AND OTHER FACILITIES IN THE AREA.

1. (A) HAVE YOU EVER TRAVELLED TRAILS IN THIS AREA BEFORE THIS TRIP?
☐ Yes (if yes, ask):
☐ No (if no, skip to question 3)

(B) EARLIER THIS YEAR?
☐ Yes (if yes, ask):
☐ No (if no, skip to question 2)

(C) WHICH TRAILS WERE YOU ON THIS YEAR BEFORE THIS TRIP? ____________
____

2. ABOUT HOW OFTEN HAVE YOU USED THE TRAILS IN THIS AREA PREVIOUS TO THIS YEAR? (Probe for both years and times)

Years:	Times:
☐ 1 year	☐ 1 time
☐ 2 years	☐ 2 times
☐ 3-5 years	☐ 3-5 times
☐ 6-10 years	☐ 6-10 times
☐ More than 10 years	☐ More than 10 times

3. HOW DID YOU HAPPEN TO PICK THIS PARTICULAR AREA FOR YOUR TRIP RATHER THAN SOME OTHER?
☐ Friends told us about it
☐ Close to home
☐ Found it by chance
☐ Been here before and liked it
☐ Other: ____________

4. (A) ARE YOU A MEMBER OF AN OUTDOOR CLUB?
☐ Yes (if yes, ask):
☐ No (if no, skip to question 5)

(B) WHICH ONE? ____________________

(C) IS THIS TRIP SPONSORED BY YOUR CLUB?
☐ Yes ☐ No

5. HOW LONG HAVE YOU BEEN IN THE AREA AWAY FROM ROADS?
☐ Less than 1 day
☐ Overnight to 3 days
☐ 4-7 days
☐ 8 days to 2 weeks
☐ Over 2 weeks

FIELD INTERVIEW QUESTIONNAIRE--Form B--page 2

6. (A) WHERE DID YOU ENTER THIS AREA? (probe) ____________

(B) ARE ALL MEMBERS OF YOUR STARTING PARTY HERE WITH YOU NOW?
☐Yes ☐No. (probe) No. entering: ______

7. WHERE IN THE AREA DID YOU GO? ____________

8. WHERE IS YOUR HOME? (city & state) ____________

9. WHAT IS YOUR ADDRESS IN (name of city)? ____________

10. HOW DO YOU SPELL YOUR NAME? ____________

11. WHAT IS YOUR OCCUPATION? ____________

12. (A) BY WHAT MEANS OF TRAVEL DID YOU ARRIVE AT THE POINT WHERE YOU ENTERED THIS AREA?
☐Motor vehicle
(if motor vehicle, ask):
☐Other (what?): ____________
(Skip to question 13)

(B) DID YOUR PARTY ARRIVE IN MORE THAN ONE VEHICLE?
☐Yes
(if yes, ask):
☐ No
(if no, ask):

(C) (1) WHAT ARE THE NAMES OF THE OWNERS?
☐Registrant owns one
☐Other owners (names):
____
____

(2) DOES THE VEHICLE BELONG TO YOU?
☐No
☐Yes
(skip to 12)

(3) WHAT IS THE OWNER'S NAME?
____

13. WHAT WAS THE MAJOR PURPOSE OF THIS TRIP?
☐Recreation (what?): ____________ ☐Work (what?): ____________

14. DO YOU HAVE ANY FURTHER COMMENTS ABOUT THIS AREA? (Write key words to remarks at time of interview. Detail remarks after interview).

THANK YOU FOR YOUR HELP. HAVE A GOOD TRIP HOME.

15. ☐ Total number of persons in group
16. ☐ Total number of pack stock
17. ☐ Total number of riding stock.
18. Recreation equipment visible: ______
____

19. Age and sex distribution of group:
____females older than 12
____females younger than 12
____males older than 12
____males younger than 12

Interview date: ____________ Interview time: ________ a.m. p.m. Trail Number: ________
Trail Name: ____________ Interviewer's initials: ________

Interviewer: Make additional comments on back!

GPO 987-554

epicormic branching of SITKA SPRUCE

by FRANCIS R. HERMAN

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPT. OF AGRICULTURE · FOREST SERVICE

U.S. FOREST SERVICE
RESEARCH PAPER PNW-18
1964

U.S. FOREST SERVICE
Research Paper PNW-18

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PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
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INTRODUCTION

Epicormic branching is characteristic of Sitka spruce *(Picea sitchensis* (Bong.) Carr.) even when the tree grows in dense stands with a closed crown canopy. When spruce stems are exposed to increased light through thinning or other stand disturbance, the formation and growth of epicormic branches is apparently stimulated (Isaac 1940, Ruth 1958).[1]

The presence of epicormic branches does not directly affect the utility of spruce saw logs for pulpwood or structural grades of lumber but does lower their value for clear lumber or for veneer. Epicormic branches also increase harvest costs because extra limbing is necessary in the woods and a larger quantity of slash remains after logging. For these several reasons, foresters need better information on the epicormic branching habits of Sitka spruce and may have to give this species special attention when carrying out thinnings or other silvicultural treatments that open up spruce stands.

This study was undertaken to explore (1) effects of light thinning on development of epicormic branches, (2) effects of road right-of-way clearing on the branching of border trees, and (3) the origin and development of epicormic branches.

EFFECTS OF LIGHT THINNING

In 1952, epicormic branches were observed immediately after thinning on 57 selected sample trees in a 100-year-old Sitka spruce-western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) stand on the Cascade Head Experimental Forest near Otis, Oreg. Before thinning, basal area was 450 square feet in 168 stems per acre. Thinning reduced basal area 20 percent to 360 square feet in 130 stems. Sitka spruce made up about one-third of the basal area before and after thinning. Spruce trees were among the largest in the stand although some were smaller than the average stand diameter of 24 inches. Sample trees ranged in d.b.h. from 13 to 44 inches.

Thinning caused no important opening up of crown canopy. Few, if any, truly vigorous trees were cut in the relatively light thinning. Most trees selected for cutting were in the intermediate or suppressed crown classes. This little reduction in crown closure was rapidly replaced by the fast-growing residual trees. In 1962, crown canopy appeared uniformly dense, so dense that photography within the stand was difficult, even with high-speed film. Basal area increased to more than 380 square feet by 1960--a 20-square-foot increase in 8 years following thinning.

---

[1] Names and dates in parentheses refer to Literature Cited, p. 9.

Vigor and abundance of epicormic branching on Sitka spruce were classified and recorded in 1952, 1959, and 1962 as defined below:

Vigor of epicormic branching:

Developing.--Many new branches emerging from the tree bole--short (1 to 6 inches) and vigorous in appearance, sometimes in addition to existing epicormic branches and also developing on them.

Stable.--Dominant branches of clusters at least 6 inches long and displaying a fair amount of vigor; bole supporting a scattering of dead branches or dead twig tips as well as a few small, single, new shoots.

Declining.--Live branches rarely exceeding 2 feet in length, and branch clusters dying with just one or two small shoots still living; dead branches, as well as a few small live branches, usually on the bole.

Abundance of epicormic branching:

Light.--Sporadic tiny clusters and individual branches not over 1 foot in length.

Medium.--Clusters and individual branches spaced irregularly on the bole, with a few large clusters having branches up to 2 feet in length.

Heavy.--Full clusters either part way or all around the bole, no more than 6 feet apart on the main portion of the bole above 20 feet.

A designation of "clear" was used for sample trees having no visible epicormic sprouts.

Of 57 trees observed in the unthinned stand, only 9 trees or 16 percent were free or "clear" of epicormic branching in 1952. Six of these trees were still clear of sprouts 10 years later. Epicormic branches on two of the three other trees, originally clear, were rated "stable-light." The third tree had died--cause of mortality not discernible.

On 48 trees with epicormic branches in 1952, the branching tended to become "stable" during the 10-year period after thinning (fig. 1). Chi-square tests of independence were made to determine the changes in sprouting since 1952. While inconclusive because of extreme variability, the analyses showed that some increase in vigor and abundance took place. Many trees classed as having "declining" epicormic sprouts in 1952 tended to be invigorated after light thinning and by 1962 assumed a "stable" status.

A shift in abundance of epicormic branching from "light" and "medium" to "heavy" took place during the 10 years following thinning (fig. 2). Six percent

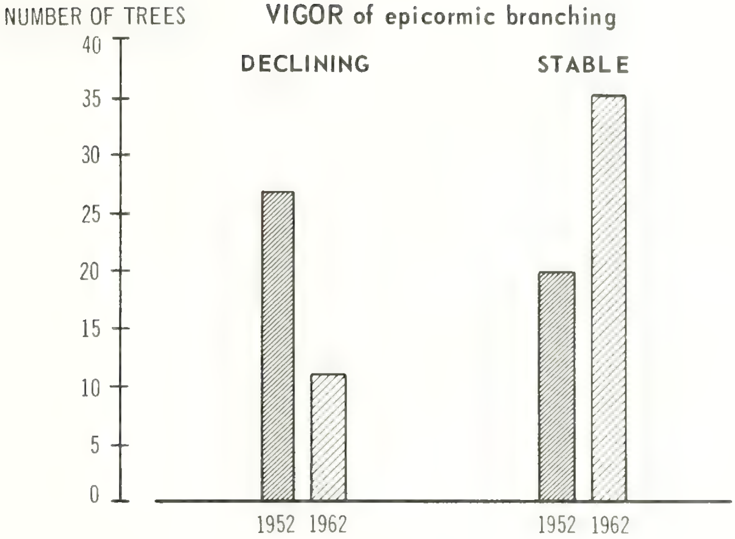

Figure 1.--Ten-year change in vigor of epicormic branching on Sitka spruce.

Note: Two trees died between 1952 and 1962.

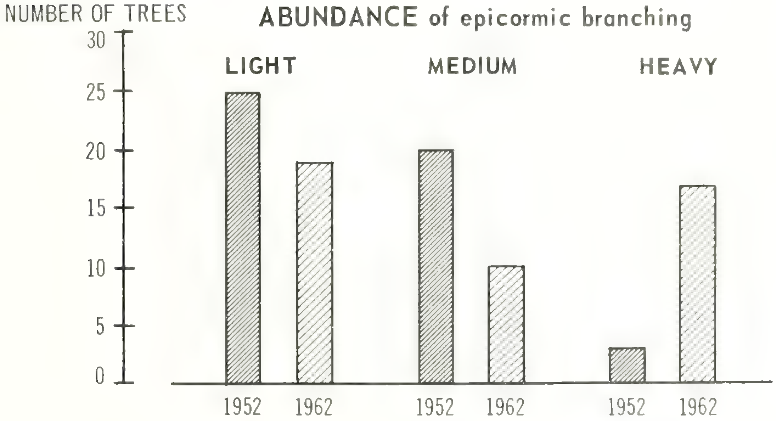

Figure 2.--Ten-year change in abundance of epicormic branching on Sitka spruce.

Note: Two trees died between 1952 and 1962.

of the 48 trees in 1952 were classified as having "heavy" epicormic branching. More than 35 percent had "heavy" branching in 1962.

Although many trees in the "declining" vigor category in 1952 assumed a "stable" sprout-vigor status in 1962, no trees had "developing" sprouts in 1962. No observational data are available for the years soon after thinning; therefore, no description of developing sprouts can be given. However, one study tree, intermediate in the crown canopy in 1959, was observed to have "developing-medium" (in 1952, rated "stable-light") epicormic sprouts. Three years later, the tree was dead. Sprouting has been observed on other obviously dying spruce trees unable to compete for crown space because of crowded stand conditions. Perhaps physiological imbalance, brought about by imminent death of these individuals, set up processes conducive to sprouting (Wahlenberg 1950, Kramer and Kozlowski 1960).

Actually, only limited sprout growth took place during the 10-year observational period--most of this in the form of invigoration and continued slow elongation of epicormic branches present in 1952. Some new sprouts developed on trees still living in 1962. Repeat photographs of some of the study trees support these observations (figs. 3a and 3b).

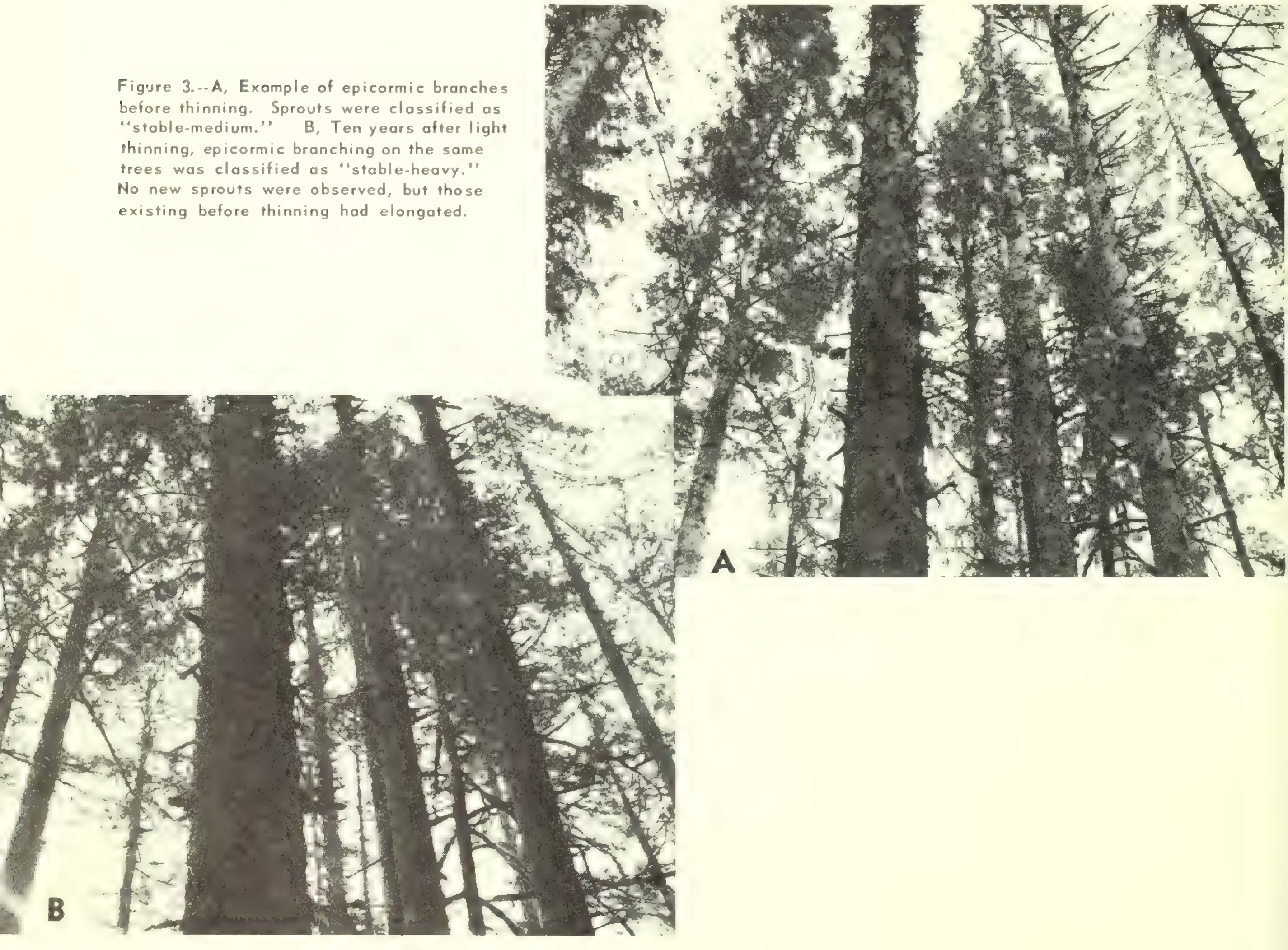

Figure 3.--A, Example of epicormic branches before thinning. Sprouts were classified as "stable-medium." B, Ten years after light thinning, epicormic branching on the same trees was classified as "stable-heavy." No new sprouts were observed, but those existing before thinning had elongated.

EFFECTS OF ROAD RIGHT-OF-WAY CUTTING

Internodal growth of epicormic branches of Sitka spruce was investigated in 1963 on trees along a logging road right-of-way established 7 years earlier. Trees bordering the right-of-way were profusely covered with epicormic sprouts, many of which predated the roadway clearing. Fifteen of these 110-year-old spruce trees were selected for study. Internodal growth was measured on epicormic branches along the side of the bole facing the clearing.

Epicormic branches showed a trend toward accelerated growth which was significant at about the 8-percent level of probability (fig. 4). While not conclusive, this result supports general observations that elongation of epicormic branches tends to accelerate when trees are exposed to increased light. However, growth acceleration was more gradual than spectacular. Supposition that growth of existing branches would increase rapidly when trees were released suddenly and completely, as along a new right-of-way, was not supported.

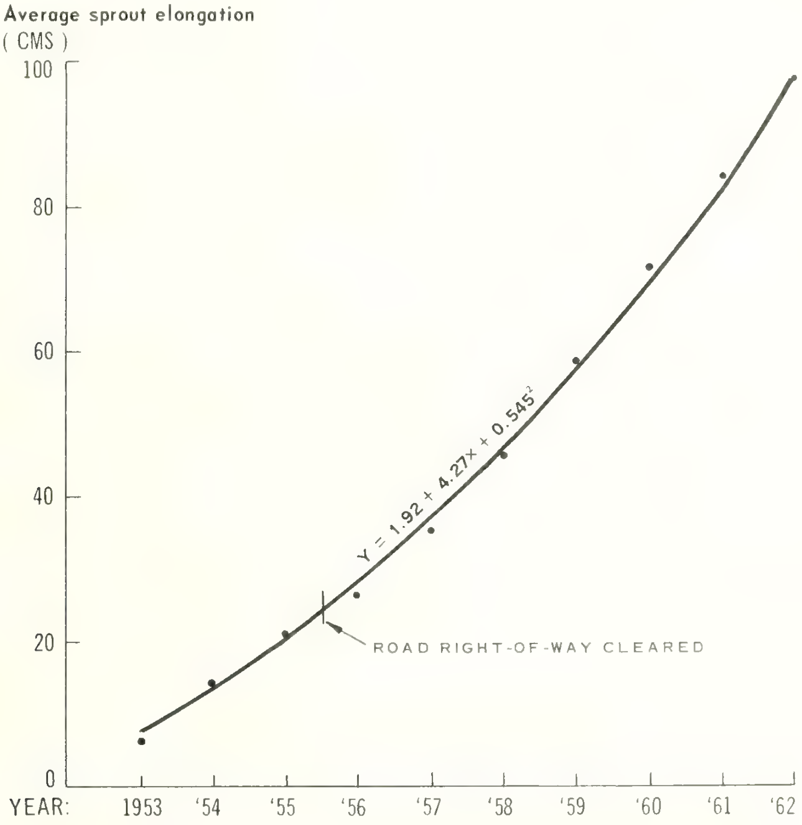

Figure 4.--Average total elongation of Sitka spruce sprouts along road right-of-way.

Concomitant observations of unreleased trees in stands behind the right-of-way border trees showed epicormic sprouts were shorter than those of their released neighbors. Border trees had fewer small, dead, lateral branches, and their needles were more abundant, longer, and larger in diameter. All border trees had more and longer sprouts on the side toward the road clearing.

ORIGIN AND DEVELOPMENT OF EPICORMIC SPROUTS

Epicormic sprouts can develop from either dormant or adventitious buds (Stone and Stone 1943b, Wahlenberg 1950). However, most sprouts originate from dormant buds at the end of bud strands (Stone and Stone 1943a, Stone 1953). These strands originate in the pith and primary xylem of the parent stem or branch. As the stem or branch grows in diameter, the bud strand grows with it, and the dormant bud continues to lie just under or at the surface of the bark.

In a study of the origin of epicormic sprouts of Sitka spruce, several short bolts containing branches were cut from 110-year-old trees. More than a dozen radial sections were carefully cut to expose dormant bud strands. These strands were traceable from pith to bark. The bud strand is believed to originate in the leaf axil together with the primary bud that develops into the original live branch (Stone and Stone 1943a). Except near the stem pith of the tree, the strand was found in a line perpendicular to stem surface. Next to the pith, it sloped upward from pith toward stem surface (fig. 5). This bend is opposite to that observed in *Eucalyptus* spp. (Jacobs 1955).

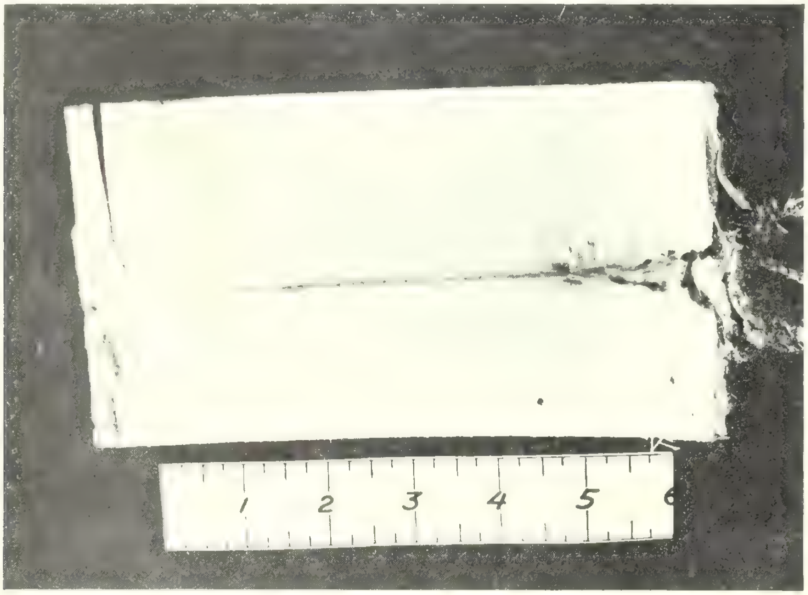

Figure 5.--Bud strand grew radially outward from pith of stem. Initially, growth was upward, but later it became horizontal.

Initially, as bud strands of Sitka spruce grow upwards, they are also displaced laterally, thus circumventing the wood of the swelling limb base. Dormant bud tissue at the junction of a newly formed leader and a lateral is believed to be located above rather than below the lateral, and consequently initially proceeds upward as new xylem is laid on. Beyond the swelling influence of the parent branch base, the strand proceeds at a right angle to the longitudinal axis of the stem, as described by Jacobs (1955) for eucalypt and by Berntsen (1961) for red alder *(Alnus rubra* Bong.).

In contrast to Sitka spruce, epicormic bud strands of eucalypt grow in a line below that of the parent branch. Because the strand proceeds in a line at a right angle to the bole surface as the wood is laid on, the dormant bud or epicormic sprout is normally below that of its parent branch (Jacobs 1955). The position of Sitka spruce epicormic sprouts in relation to their parent branches was not as consistent, probably because of the spruce habit of near-horizontal branching. A few of the spruce strands were found above a parent branch stub where the branch apparently grew downward. However, most strands were found below or alongside a parent branch.

Spruce with diameters from 10 to 40 inches were examined to determine if divergence increased between dormant bud strand and parent branch as the tree grew larger. Analysis of measurement data showed that the larger the stem, the farther were the dormant buds or epicormic sprouts from the parent branch (fig. 6).

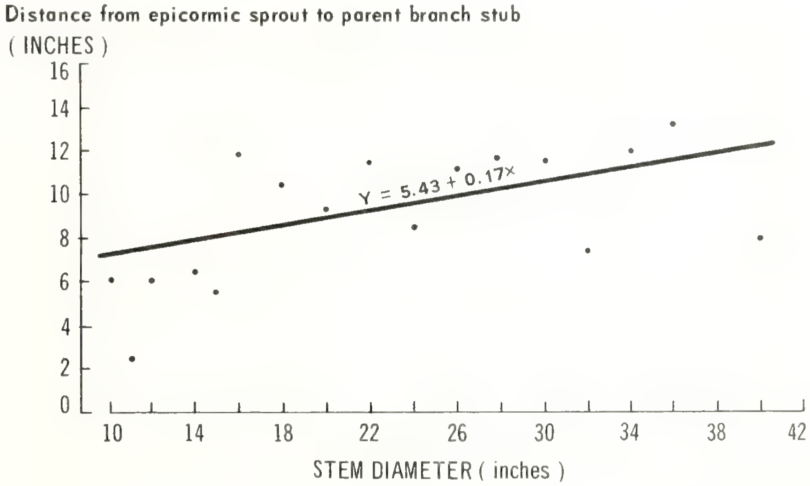

Figure 6.--Relationship of Sitka spruce stem diameter to distance between epicormic sprout and parent branch.

DISCUSSION AND SUMMARY

Experience gained in these exploratory studies and concomitant field observations suggests that perhaps the most limited of cuttings would tend to at least maintain established sprouts and might even stimulate additional sprouting. Spruce in unthinned 110-year-old stands usually supported at least a few epicormic sprouts. Perhaps the presence of a few sprouts is normal, at least for stands of this age class and density.

Thinning 20 percent of basal area in a 110-year-old stand containing Sitka spruce did not cause significant increases in abundance of epicormic branching. However, epicormic sprouts growing at time of thinning continued to grow with some increase in vigor. Growing conditions apparently were not so marginal as to cause them to die. Nor were postthinning conditions so favorable as to suddenly accelerate internodal elongation of existing sprouts or production of new sprouts.

Most study trees that were clear of sprouts before thinning did not produce epicormic branches after thinning. It is reasonable to suspect that genetic differences exist in reference to degree of sprouting ability. That these differences are associated with varying initial production of dormant bud tissue or with varying response to level of light intensity can only be speculated.

Exposure of 110-year-old Sitka spruce stems to increased solar radiation by cutting a logging road right-of-way resulted in increased growth of existing epicormic branches and production of new ones. Accelerated sprout development following marked release has also been noticed in younger, denser stands, which displayed only occasional sprouts prior to release.

Apparently moderate or heavy thinnings will stimulate epicormic branching of Sitka spruce. Future production of high quality spruce veneer and lumber is, therefore, unlikely unless supplementary measures can be taken to suppress sprouting. In contrast, sprouting should have little influence upon quality of pulpwood and structural lumber and may not be a serious factor where these products are the primary goal of management.

In summary, the most significant observations in this study were:

1. Most Sitka spruce trees in a 100-year-old stand had some epicormic branching prior to any release.

2. Light thinning resulted in some invigoration and continued slow elongation of existing sprouts.

3. New sprout production during the succeeding 10 years was slight.

4. Road right-of-way clearing (heavy release) tended to stimulate new sprouting and vigor and growth of existing sprouts, although not spectacularly.

5. Sprouts were formed from dormant buds, with bud strands clearly traceable to the pith.

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VEGETATION-SOIL UNITS in the central Oregon juniper zone

by Richard S. Driscoll

13.78: PNW-19

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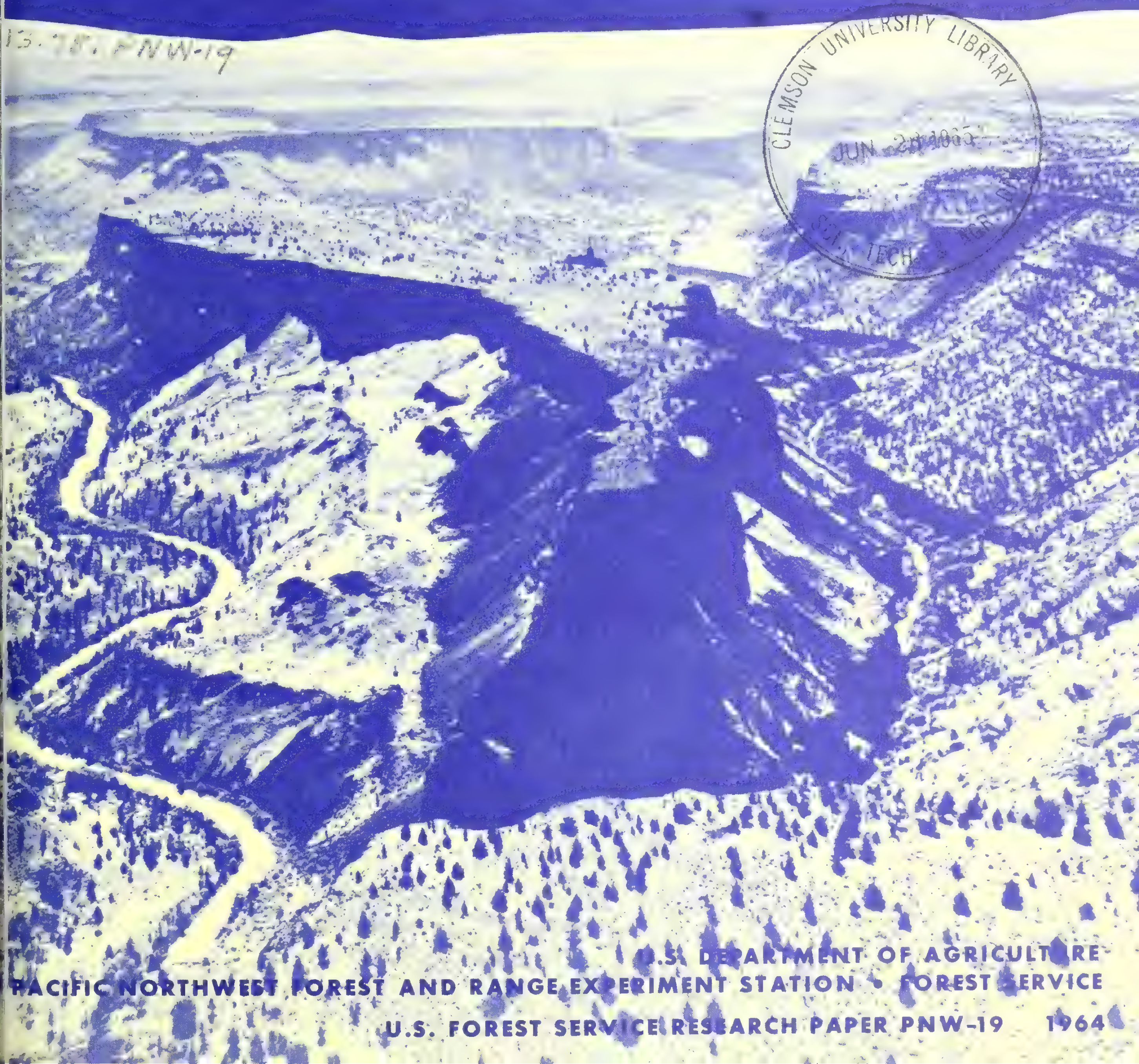

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PACIFIC NORTHWEST FOREST AND RANGE EXPERIMENT STATION • FOREST SERVICE
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Introduction

Efficient and successful land management is more likely when the landscape is classified into natural ecological units of effective environment. Such a system of classification must include several characteristics specific to each unit so that the units may be readily recognized and identified even though some characteristics may be altered or destroyed. Since plant communities and the soils supporting them are functional products of the same longtime environmental interactions, characteristics associated with the two complexes and an understanding of their relationships provide the basis for the needed classification.

A classification designed in this manner is not available for the central Oregon juniper zone, even though the area has long been used for grazing and agricultural crop production. In fact, few scientific investigations have been made to provide any knowledge of the ecology of the area. Jensen (1945)[1] developed empirical standards to classify range conditions in the "grassland-juniper" type in central Oregon, but he supplied little quantitative data concerning characteristics of the virgin area and did not attempt to classify particular plant communities. Eckert[2] classified vegetation-soil units in some *Artemisia*[3] types in northern Harney County in eastern Oregon. *Juniperus occidentalis* occurs in some of these communities, but these units are not distinctive of the juniper zone. Numerous other studies describing plant communities where juniper species occur in the Western United States have been made (Cottle 1931, Emerson 1932, Merkle 1952, Rasmussen 1941, Woodbury 1947, Woodin and Lindsey 1954). However, the results of these have little direct bearing on the ecology of the central Oregon juniper zone.

This work defines and characterizes some vegetation-soil units represented by relatively undisturbed areas. The units were interpreted on the basis of holistic and polyclimax concepts of ecology (Billings 1952, Daubenmire 1952, Tansley 1935). Vegetation, soil, and topographic relationships having a bearing on identification and classification of disturbed places in the study area are discussed as well as some thoughts on how the results may be used in a practical manner.

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[1] Names and dates in parentheses refer to Literature Cited, p. 46.

[2] Eckert, Richard Edgar, Jr. Vegetation-soil relationships in some *Artemisia* types in northern Harney and Lake Counties, Oregon. 208 pp. 1957. Ph.D. thesis on file Oregon State University.

[3] A list of common and scientific plant names is in Appendix 1.

CORRECTION

Driscoll, Richard S. Vegetation-soil units in the central Oregon juniper zone. U. S. Forest Serv. Res. Paper PNW-19

In figure 1 on page 2, the top and bottom symbols of the legend should be reversed.

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The Area

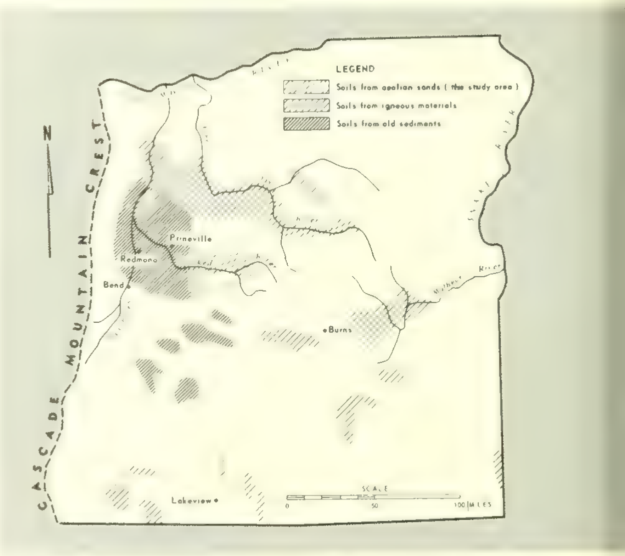
Physiography

The central Oregon juniper zone includes approximately 108,000 acres in Crook, Deschutes, and Jefferson Counties where western juniper is a major component of the vegetation. This area is one of three physiographic subdivisions of the Northwest representative of the pinyon-juniper zone in the Western United States. Although no pinyon pines occur in the Oregon area, other features are similar to the broad parent zone. Soils are generally shallow and stony. The climate is characterized by high summer temperatures, cool winters, high winds, low relative humidity, and low annual precipitation. In the study area, the zone grades to the ponderosa pine zone, where moisture is more effective, and to the sagebrush or grassland zones of less effective moisture.

The three physiographic subdivisions are based on soil parent materials (fig. 1). In the study area, soils are derived from wind-laid and mixed igneous and pumice sands or, where these materials do not comprise the actual parent material, pumice is scattered throughout the soil profile. Where pumice is present, but not as a major soil forming material, it is found mostly in the A horizon. The pumice probably originated from Mount Mazama (site of Crater Lake), 100 miles southwest of Bend, when the volcano exploded approximately 8,000 years ago (Williams 1942). Some pumice may have originated from more recent eruptions of Newberry Crater (site of Paulina and East Lakes), located 25 miles south of Bend. The igneous sands, mostly from andesite, rhyolite, or basalt, were transported from dry lakebeds by southwesterly winds.

A second physiographic subdivision of the Oregon juniper zone has soils derived mostly

Figure 1.—Distribution of the physiographic subdivisions of the juniper zone in eastern Oregon.



of igneous materials. This soil forming substance is varied, comprised of rhyolitic, andesitic, or basaltic lava flows which occurred over long periods of geologic time. Some of the oldest flows originated during the Miocene epoch (Hodge 1942). Others occurred intermittently up to Recent time.

The third physiographic subdivision has soils derived primarily from sedimentary materials and is located principally in the upper regions of the John Day and Crooked Rivers. These sediments, primarily the Clarno and John Day formations, were water deposited during the Eocene and Oligocene epochs (Kellogg 1927).

Climate

The regional climate of the study area is continental, modified by marine air currents from the Pacific Ocean. It is semiarid, characterized by low annual precipitation, dry summers with warm days and cool nights, and cool-to-cold, relatively snow-free winters. No month is frost free, although killing frosts generally do not occur during June, July, and August.

Annual precipitation varies greatly by locality and year. At Bend, located in the transition between the juniper and ponderosa pine zones, the average annual precipitation, based on 56 years of record, is 12.25 inches (U. S. Weather Bureau 1959). The highest recorded was 25.95 inches in 1907 and the lowest recorded was 5.75 inches in 1959. At Redmond, 20 miles north of Bend and in the center of the area, the average annual precipitation, based on 29 years of record, is 8.54 inches with a high of 14.19 inches in 1948 and a low of 4.39 inches in 1949. Approximately 88 percent of the annual precipitation occurs as rain and snow fairly evenly distributed from October through June. The summer months are droughty, frequently completely dry. Precipitation that does occur during the summer is ineffective for perennial plant growth because of low-intensity storms (usually less than 0.25 inch per storm) and high day temperatures (usually exceeding 80° F).

When the study was made, 1959 and 1960, the area suffered one of the severest droughts on record. Table 1 summarizes precipitation data for these 2 years, computed on an October-June forage-year basis to show departures, totals, and long-term means at Bend and Redmond. This untimely climatic sequence undoubtedly influenced plant growth, particularly herbaceous species, resulting in a climatic bias of the vegetation data.

Topography and Geology

The elevational range of the study area varies from 2,200 to 5,000 feet above sea level. The western part of the area is characterized by a

Table 1.—Departures, totals, and long-term means for 1958-59 and 1959-60 forage-year precipitation at Bend and Redmond, Oreg.[1]

Station and year	Month									Forage-year total
	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	
	Inches									
Bend:										
1958-59	-0.61	-0.75	-1.18	-0.59	0.41	-0.03	-0 61	-0.39	-0.95	-4.70
1959-60	- .49	-1.19	-1.15	- .58	.40	1.52	.22	- .54	-1.24	-3.89
Mean	.93	1.45	1.83	1.85	1.03	.76	.68	1.12	1.25	10.90
Redmond:										
1958-59	- .67	.56	.13	- .02	30	- .56	- .58	- .47	- .43	-1.74
1959-60	- .11	- .60	- .92	.89	.45	1.38	- .11	- .24	-1.08	- 34
Mean	.69	.90	1.11	1.04	.70	.56	.58	.82	1.08	7.48

[1] No sign or minus (-) sign indicates positive or negative departures from means.

nearly level to rolling upland plain dissected by deep V-shaped gorges of the Deschutes and Crooked Rivers. The eastern part is characterized by numerous buttes rising from 500 to 1,500 feet above the floor of the plain.

The plain area is highly variable. South of the Crooked River, it is interlaced by ropey, basaltic lava flows of Recent time. Deep sands of mixed pumice, andesite, rhyolite, and basalt occur between the lava flows. North of the Crooked River, occasional diastrophic buttes composed of John Day and Clarno sediments have been uplifted 500 to 1,500 feet above the plain floor. Among these buttes, highly variable alluvial material of the Madras and Cascan formations occurs. A relatively large quantity of pumice is mixed with this material. Occasional pumice "pockets" of varying area and depth occur throughout the plain area.

Some of the buttes in the eastern part of the study area have lava flows dating from Recent time, but most buttes appear to have been formed by diastrophism. Occasional "cinder cones," low cone-shaped buttes with extensive volcanic cinder deposits on their slopes, occur in the central part of the area near Redmond. The diastrophic buttes are heterogeneous. Most of them are capped with rhyolitic and/or andesitic lavas. Tuffaceous sediments appear beneath the lava flows. Sand deposits of similar appearance to those found among the lower lying lava flows occur on the lee side of the buttes and ridges.

Soils

The soils in the area are in the Sierozem, Brown, and Chestnut great soil groups (Knox 1957). Brown soils and their associated Azonal Regosols are most common. The Chestnuts are minor in extent, occurring mostly on north and northeast slopes where temperature and precipitation have favored their development. Sierozems are also limited, occurring in the hotter, drier portions of the area.

The soils are mostly light colored, with gray to light-yellowish-brown A horizons and accumulations of soluble salts or siliceous materials on individual soil peds or rocks in the profile. They are low in organic matter and have low carbon-nitrogen ratios.

Most of the soils are sandy loams, but textures range from loamy coarse sand to clay loam. Structure in the B horizon ranges from strongly developed prismatic to weak subangular blocky. Many of the soils lack B horizons. In most cases, large volumes of the solum are occupied by stones.

The depth of the solum ranges from 14 to 44 inches but is generally around 30 inches. The underlying materials affecting plant growth include solid or cracked bedrock, hardpans which are often discontinuous, or semiconsolidated mixtures. The cracked bedrock usually has thin films of soil in the cracks, allowing deeper root penetration than might be expected. Some of the "apparent" bedrock becomes loose and friable when moist, providing an acceptable medium for root growth.

Vesicular plates are common on the surface of most of the undisturbed soils. The role of these 1- to 2-inch-thick plates in plant growth and distribution is not well understood.

The soil surface is slightly acid (pH 6.0) to neutral (pH 7.0). Soil reaction increases with depth, becoming slightly alkaline (pH 7.5) to alkaline (pH 8.0) at the bottom of the B horizon. White calcareous or siliceous deposits on individual soil peds or on the undersides of rocks are common in the subsoil.

Although a soil survey has been conducted on lands used for farming within the study area (Leighty 1958), none of the classified units was observed during this study.

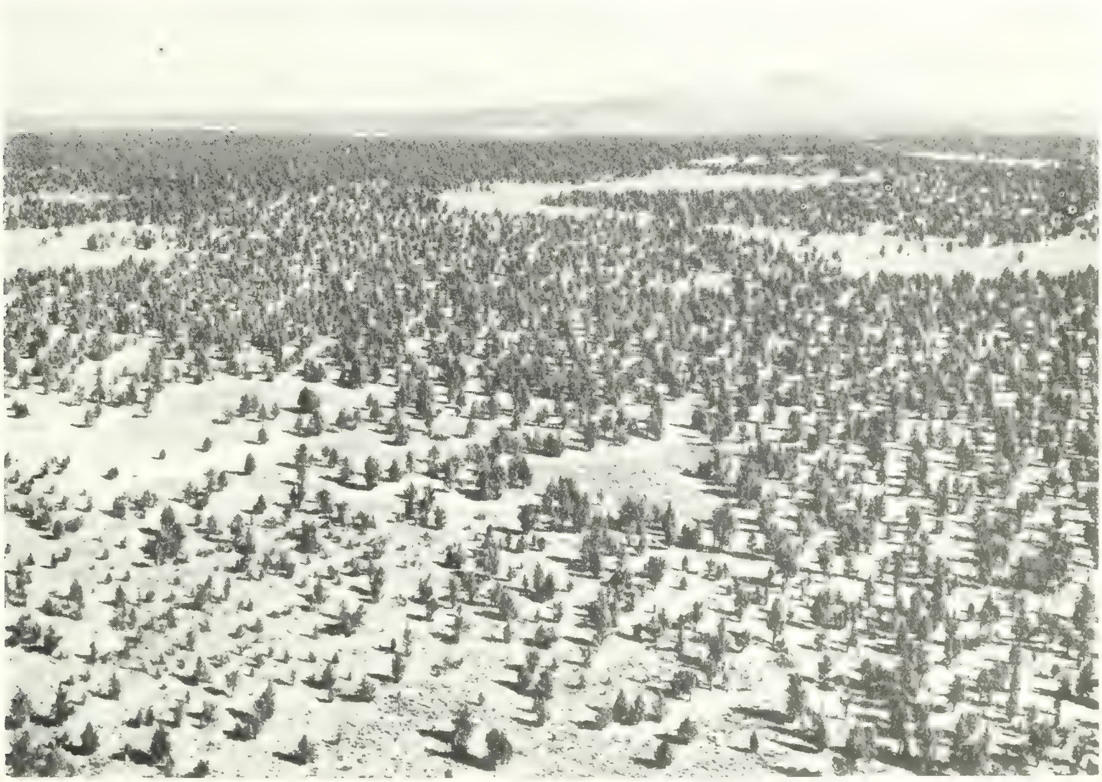
Vegetation

Juniperus occidentalis is the dominant tree species of the area. An occasional *Pinus ponderosa* may be found in canyon bottoms or on north slopes where soil moisture is more effective. Natural wide spacing of individual junipers provides the aspect of a savanna (fig. 2). *Artemisia tridentata* is most often the dominant shrub in the understory. Occasionally it is displaced wholly or to codominance by *Purshia tridentata*. Other shrubs characteristic of the area are *Chrysothamnus nauseosus*, *C. viscidiflorus*, *Tetradymia canescens*, *Leptodactylon pungens*, and *Artemisia arbuscula*. *Ribes cereum*, *Grossularia velutina*, and *Grayia spinosa* occur infrequently. Suffrutescents are represented by various species of *Eriogonum*.

Agropyron spicatum and *Festuca idahoensis* are the characteristic grasses of relatively undisturbed communities. *Poa secunda* and *Stipa thurberiana* are common. Other grasses include *Sitanion hystrix*, *Stipa comata*, *Bromus tectorum*, *Festuca octoflora*, and *Koeleria cristata*.

Forbs commonly do not constitute major components of relatively undisturbed communities. Some of the more common perennial forbs are *Agoseris* sp., *Achillea millefolium*, *Eriophyllum lanatum*, *Astragalus* spp., *Erigeron linearis*, and *Lupinus* spp.

Figure 2.—Wide spacing of individual trees provides the characteristic savanna aspect of the central Oregon juniper zone.



Methods

Prior to making detailed measurements, plant associations[4] were classified on a tentative basis by reconnaissance. Insofar as possible, these units represented areas relatively undisturbed by grazing or other land uses. This initial separation was based primarily on the vegetational physiognomy of the units. Also considered were soil characteristics including amount of bare soil surface, soil stoniness, solum depth, and nature of the underlying material. Although subjectivity in this initial classification is implied, it is tolerable. Greig-Smith (1957) emphasizes that areas subjectively selected as being distinctive and not transitional on the basis of predefined criteria are evidence they represent specific entities.

For each association recognized from the initial reconnaissance, five 50- by 100-foot macroplots were located in representative stands with care taken to avoid ecotones. Within each macroplot, four 50-foot combination line-belt transects were located in restricted random fashion. Along each transect, ten 1- by 2-foot observation plots were systematically placed. This sampling scheme has been discussed by Poulton and Tisdale (1961).

Measurements of vegetation included: (1) percent foliage cover of individual species, (2) percent basal area of perennial herbs, (3) average maximum heights of mature, shrubby, and suffrutescent species, and (4) density counts of shrubby and suffrutescent species. Related data were obtained on the percentage of the soil surface not occupied by living or dead plant material.

Percent foliage cover of all herbaceous species, basal area of perennial herbaceous species, and bare soil surface were ocularly estimated on the small observation plots. Foliage cover of shrubs was measured by the line intercept method (Canfield 1941) on the 50-foot line transects. Shrub density was obtained by counting all individuals rooted in a 4-foot belt transect bisected by each line transect. Average maximum heights of mature shrubs were determined by measuring all mature plants within the belt transect. Percent foliage cover of trees was estimated over the whole of each association from aerial photographs (Moessner 1960). In addition, percent constancy of all species was computed on the basis of presence or absence within the bounds of the macroplots.

Soil data were obtained from pits dug immediately adjacent to each macroplot. Profile characteristics were described in accordance with procedures outlined in the Soil Survey Manual (U. S. Bur. Plant Indus., etc. 1951) and tentative taxonomic soil units were established[5]. In addition, samples of the A horizon and the finest textured part of the B horizon, or the AC horizon of the Regosols, were collected and analyzed for (1) textural classes, (2) moisture equivalent, (3) 15-atmospheres tension, (4) bulk density, and (5) soil reaction (pH). In addition, percentages of organic matter and total nitrogen were determined for the A horizon.

---

[4] An association is ". . . the fundamental unit of phytosociology, being a plant community of certain floristic composition, of uniform habitat conditions and of uniform physiognomy" (Wildeman 1910). The term as used here is applied only to climax communities defined according to polyclimax concepts.

The results of analyses for moisture equivalent, 15-atmospheres tension, and bulk density were used to compute the total available water storage capacity in the 2- to 14-inch soil zone (Broadfoot and Burke 1958). All soil analyses were made by the Soil Testing Laboratory of the Oregon Agricultural Experiment Station at Corvallis.

Slope aspect was determined by a compass and recorded as one of the eight points, i.e., northeast, south, southwest, etc. Elevation at each macroplot was measured with an aneroid barometer. Slope position is the place on slopes where macroplots were located and was estimated as to the upper, middle, or lower one-third.

No attempt was made to determine the areal extent of the classified units or to determine the sequence pattern of secondary succession.

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[5] Descriptions of these units are presented in Appendix 2. Descriptions and unit interpretations were reviewed by Drs. C. T. Youngberg and E. G. Knox, soil specialists, Oregon State University.

Results

Classification of the Units

Relatively undisturbed plant communities show the integrated results of longtime environmental interactions. The floristics of the communities, particularly the dominants in the different community layers and the character and sociability of species, provide clues to the classification of homogeneous ecological entities. Associated abiotic factors, considered as independent and interacting influences on the communities, provide additional evidence for separating the units. On this basis, each plant association subsequently classified and described, together with its related soils and topographic characteristics, represents a component part of an individual ecosystem.

This investigation provided a classification scheme in which the vegetational and soil components of nine ecosytems and variants of two were named and characterized on the premise that they exist as demonstrable entities with both independent and intergrading characteristics. The variants are subunits very closely related to one of the classified entities but differ strongly from the entities in at least one differentiating characteristic. However, other evidence obtained did not seem to warrant classification of these subunits as separate systems. In all cases, primary vegetational and soil features selected for classification and characterization purposes were those which had become adapted to and expressed most fully the time and space relationships of the whole environment of the particular system. In some cases, constancy data were used to support unit separations based on the measured characteristics.

The generalized characteristics of the vegetation-soil units are shown in table 2. The entities are arranged in descending order of effective moisture interpreted on the basis of combined vegetative, soil, and topographic characteristics. The units were named according to the generic names of the most abundant plants in the tree, shrub, and herbaceous layers of each association. Generally, trinomial nomenclature was found adequate to briefly convey the vegetational physiognomy of the units. In some units, however, character species were the same but differed in dominance. This occurred between the *Juniperus/Artemisia/Festuca* and *Juniperus/Artemisia/Festuca-Lupinus* associations. In this case, the generic name of a forb showing 100-percent constancy in one association and considerably less in the other was used to differentiate the two units in name. Occasionally, one plant layer contributed little to the physiognomy of the community and binomial nomenclature was adequate. This occurred in the *Juniperus/Festuca* and *Juniperus/Agropyron* associations. Sometimes, two species of similar life-form were nearly equal in

Table 2.—Number of macroplots and generalized characteristics of vegetation-soil units in the central Oregon juniper zone

Unit	Sample units	Aspect	Associated great soil group	Elevational range
		Number		Feet
Juniperus/Artemisia/Festuca	5	NW. to NE.	Chestnut	4,250-4,500
Juniperus/Artemisia/Festuca-Lupinus	4	N. to NE.	Regosol in Brown zone	4,400-4,550
Juniperus/Festuca	5	NW.	Brown	4,100-4,300
(*Purshia* variant)	(2)	(SE. to E.)		
Juniperus/Artemisia/Agropyron-Chaenactis	5	NW. to NE.	Regosol in Brown zone	3,900-4,400
Juniperus/Artemisia/Agropyron	5	Level	Brown	2,550-2,650
Juniperus/Agropyron	6	E. to NE.	Brown	4,150-4,450
(*Purshia* variant)	(2)	(SE.)		
Juniperus/Artemisia-Purshia	5	N. to NE.	Regosol in Brown zone	4,100-4,400
Juniperus/Agropyron-Festuca	5	E.	Regosol in Brown zone	4,250-4,750
Juniperus/Artemisia/Agropyron-Astragalus	6	S. to SW.	Brown	4,000-4,400

abundance in certain plant layers. In such a case, the generic names of both species were used to name the associations. The *Juniperus/Artemisia-Purshia* and *Juniperus / Agropyron-Festuca* associations are examples.

Samples of at least five stands were used to classify and characterize all but one of the associations and the two association variants. One unit of the *Juniperus/Artemisia/Festuca-Lupinus* association was sufficiently different in floristic and soil characteristics that it was discarded from the analysis. Only two sample units were used to characterize the *Purshia* variants of the *Juniperus/Festuca* and *Juniperus/Agropyron* ecosystems. These variants were minor in areal extent. The main characteristics were the same as their respective associations, and sufficient representative stands could not be located for analysis.

Direction of slope appeared limiting in the occurrence of *Purshia* and the relative dominance of *Festuca* and *Agropyron*. *Purshia* was most common on southeast- to east-facing slopes. The associations with *Festuca* as the most abundant herbaceous species favored northerly slopes. Where *Agropyron* was most abundant in the herbaceous layer, the respective associations had southerly to level aspects. Exceptions occurred with the *Juniperus /Artemisia/Agropyron-Chaenactis* and *Juniperus /Agropyron-Festuca* associations where *Agropyron* was dominant in the herbaceous layers. These units occurred on northerly to east slopes with Regosolic soils whose characteristics apparently compensated other factors to favor stronger expression of *Agropyron*.

Relationships between associations and great soil groups were meager. In one case, however, two associations identical in general physiognomy were separated on the basis of related great soil groups. The *Juniperus /Artemisia/Festuca* associations occurred with a Chestnut soil. The *Juniperus/Artemisia/Festuca-Lupinus* association occurred with a Regosol. Elevation appeared nondeterminant in ecosystem distribution in the central Oregon juniper zone.

The diagnostic features of the units were organized into a taxonomic key of the associations based on vegetational, soil, and topographic characteristics easily recognized in the field. The key provides a way to identify each unit without detailed knowledge of the entities. It will assist the reader and potential user of the results of this study to remember some basic characteristics of the recognized vegetation-soil units. Immediately following the key are detailed descriptions of associations and their related soils.

Key to the Associations

1. Associations occurring with zonal soils
   2. Associations occurring on northerly slopes with Chestnut soils of rhyolitic-andesitic colluvial origin; *Juniperus occidentalis, Artemisia tridentata,* and *Festuca idahoensis* comprising respectively 12-, 7-, and 11-percent cover _________ ***Juniperus/ Artemisia/Festuca*** association
   2. Associations occurring on varied slopes with Brown soils of varied origin
      3. *Festuca idahoensis* dominant in the herbaceous layer (approximately 11-percent cover); *Juniperus occidentalis* comprising 77-percent cover; association normally occurring on the lower portion of north slopes on soils derived from volcanic tuff indurate when dry but friable and porous when wet ___________ ***Juniperus/Festuca*** association

         Purshia variant: Occurs on east to southeast slopes; *Purshia tridentata* comprises 4-percent cover; *Festuca idahoensis* comprises 5-percent cover
      3. *Festuca idahoensis* not dominant in the herbaceous layer and may be absent; *Agropyron spicatum* dominant in the herbaceous layer
         4. *Artemisia tridentata* in very small quantities (0.9-percent cover); *Juniperus occidentalis* and *Agropyron spicatum* comprising respectively 43- and 5-percent cover; association normally occurring on east to northeast slopes with soils of rhyolitic-andesitic colluvial origin ___ ***Juniperus/Agropyron*** association

            Purshia variant: Occurs on southeast slopes; *Purshia tridentata* comprises 7-percent cover
         4. *Artemisia tridentata* in larger quantities (more than 7-percent cover)
            5. *Festuca idahoensis* absent in measured stands (present only under trees); *Juniperus occidentalis, Artemisia tridentata,* and *Agropyron spicatum* comprising respectively 28-, 7-, and 7-percent cover; *Astragalus lectulus* present in all stands; association occurring on south- and southwest-facing slopes with soils of rhyolitic-andesitic colluvial origin __***Juniperus/Artemisia/Agropyron-Astragalus*** associations
            5. *Festuca idahoensis* present in very small quantities (0.4-percent cover); *Juniperus occidentalis, Artemisia tridentata* , and *Agropyron spicatum* comprising respectively 10-, 8-, and 9-percent cover; *Astragalus lectulus* absent in all stands; association occurring on gently undulating uplands with strongly developed, almost rock-free soils of water- and/or wind-laid sediments _____ ***Juniperus/Artemisia/Agropyron*** association

1. Associations occurring with azonal Regosolic Brown soils of mixed aeolian igneous and pumice sands and found on the upper half of north to northeast slopes
   6. Associations occurring with soils developed from deep (45 inches) sands; *Artemisia tridentata* and *Purshia tridentata* sharing dominance (8- and 6-percent cover, respectively) in the shrub layer _______ ***Juniperus/Artemisia-Purshia*** association
   6. Associations occurring with soils developed from shallow (16 inches) to moderately deep (25 inches) sands, indurated hardpans present or absent

7. Associations occurring with soils developed from shallow (16 inches) sands; indurated hardpans present; *Agropyron spicatum* and *Festuca idahoensis* sharing dominance (3- and 2-percent cover, respectively) in the herbaceous layer; *Juniperus occidentalis* comprising 32-percent cover ____________ **Juniperus/Agropyron-Festuca** association

7. Associations occurring with soils developed from moderately deep (25 inches) sands; *Agropyron spicatum* or *Festuca idahoensis* dominating the herbaceous layer; indurated hardpans absent
    8. *Agropyron spicatum* dominant (4-percent cover) in the herbaceous layer; *Juniperus occidentalis* and *Artemisia tridentata* comprising 46- and 4-percent cover, respectively; *Chaenactis douglasii* present in all stands; *Lupinus* sp. absent in all stands ________ **Juniperus/Artemisia/Agropyron- Chaenactis** association
    8. *Festuca idahoensis* dominant (10-percent cover) in the herbaceous layer; *Juniperus occidentalis* and *Artemisia tridentata* comprising respectively 12- and 5-percent cover; *Chaenactis douglasii* absent in all stands; *Lupinus* sp. present in all stands __ **Juniperus /Artemisia/ Festuca-Lupinus** association

Description of the Units

Summaries of specific vegetation and soil characteristics of the classified units are presented in tables 3, 4, and 5. Table 4 is a listing of the percent foliage cover and constancy of species arranged in relative order of dominance and constancy. Table 3 summarizes selected characteristics of the soils occurring with each association. Table 5 provides a comparison among the associations of the density and height measurements of shrubby and suffrutescent species.

Table 3.—Average values of selected surface and subsoil characteristics attendant to nine associations in the central Oregon juniper zone

Association	Basal area perennial herbs	Bare soil surface	Available SMS[1] capacity, 2- to 14-inch zone	Organic matter, A horizon	Total nitrogen, A horizon	Horizon texture[2]	
						A	B or AC
	Percent	Percent	Inches water	Percent	Percent		
Juniperus/Artemisia/Festuca-Lupinus	7.4	22.1	1.41	4.78	0.21	l	c
Juniperus/Artemisia/Festuca-Lupinus	6.5	30.9	1.98	1.74	.10	sl	sl
Juniperus/Festuca (*Purshia* variant)	4.4	33.3 (46.8)	1.81 (2.14)	3.91 (2.33)	.17 (.10)	l (l)	sil, c (c)
Juniperus/Artemisia/Agropyron-Chaenactis	5.2	52.3	.87	1.59	.08	sl	sl
Juniperus/Artemisia/Agropyron	6.6	41.3	2.31	1.50	.08	l	c, cl
Juniperus/Agropyron (*Purshia* variant)	3.2	51.1	1.34	2.12	.10	scl (l)	c, cl
Juniperus/Artemisia-Purshia	3.1	55.0	1.54	1.05	.06	sl	sl
Juniperus/Agropyron-Festuca	4.1	54.7	.97	1.32	.07	sl	sl
Juniperus/Artemisia/Agropyron-Astragalus	3.5	45.7	1.21	1.63	.08	l	c

[1] SMS, soil moisture storage.

[2] The AC horizon is immediately below the A horizon in Regosols. B horizon textures were taken for the finest part of that horizon. Textural classes: cl, clay loam; l, loam; scl, sandy clay loam; sil, silt loam; c, clay; and sl, sandy loam.

Table 4.—Mean foliage cover and constancy of species in nine classified associations of the central Oregon juniper zone[1] (In percent)

Species	Association							
	Juniperus/ Artemisia/ Festuca		*Juniperus/ Artemisia/ Festuca-Lupinus*		*Juniperus/ Festuca*		*Juniperus/ Artemisia/ Agropyron-Chaenactis*	
	Cover	Constancy	Cover	Constancy	Cover	Constancy	Cover	Constancy
Juniperus occidentalis	12.0	100	12.3	100	76.7	100	46.0	100
Artemisia tridentata	7.4	100	5.1	100	.9	100	4.1	100
Festuca idahoensis	10.8	100	10.4	100	10.8 (5.3)	100 (100)	1.9	100
Agropyron spicatum	5.3	100	1.5	100	1.6	100	3.7	100
Poa secunda	1.6	100	1.0	100	.9	100	7	100
Koeleria cristata	.2	100	.8	100	.3	100	.7	100
Astragalus sp	1.4	100			.1	60		
Agoseris sp.	.4	100		25	1	40		
Achillea millefolium	.3	100			.1	60	.1	100
Lomatium triternatum	.1	100	.1	100		100		
*Collinsia parviflora**	.6	100	.1	100	.2	100	.6	100
*Gayophytum lasiospermum**	.3	100		25		80	.5	80
Lupinus sp		40	2.3	100	.1	60		
Phlox douglasii	.3	40	.3	100	2	100		
Erigeron filifolius			.3	100				
Eriogonum microthecum			.3	100				
Eriophyllum lanatum		60	.1	75	.2	100	.1	60
*Bromus tectorum**		60			.2	100	1.7	100
Stipa thurberiana			.1	75	.4	80	.7	100
Chaenactis douglasii						20	.3	100
Astragalus sp.				25		80	.2	100
*Cryptantha ambigua**		20		50	.1	80	.3	100
Chrysothamnus nauseosus		40	.2	100		20	.2	60
*Festuca octoflora**								
Sitanion hystrix		20					.1	40
Erigeron linearis		60			.1	80	.2	80
Purshia tridentata					.6 (3.5)	100 (100)	.1	60
Chrysothamnus viscidiflorus	.3	80	.2	100	.1	100	.4	60
*Collomia grandiflora**						80		
*Mentzelia albicaulis**							.1	80
*Montia perfoliata**	.3	60				20		
Eriogonum ochrocephalum				75		20		60
Astragalus lectulus						60		
Stipa comata								
Eriogonum sphaerocephalum						20		
*Linanthus harknessii**				25			.2	80
*Eriogonum baileyi**				25		60		
Eriogonum umbellatum						80		
Penstemon cinereus					.1	80		
Other perennial herbs[2]	.1		.1		.1		1.4	
Other perennial shrubs[3]	.3		1.7					
Total perennial herbs	20.5		17.0		15.1 (9.6)		10.1	
Total shrubs and suffrutescents	8.0		7.5		1.6 (4.5)		4.8	

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[1] Cover recorded for species having at least 0.1-percent cover in a single association.
Constancy recorded for species attaining 80-percent constancy or more in at least one association.
Species characteristics in parentheses indicate association variants.
Species with constancy but not cover, indicates presence in insufficient quantity to provide cover estimates.

[2] Mostly *Carex filifolia* in the *Juniperus/Artemisia/Agropyron-Chaenactis* association; variable in others.

[3] Mostly *Tetradymia canescens* in the *Juniperus/Artemisia/Festuca*, *Juniperus/Artemisia/Festuca-Lupinus*, and *Juniperus/Artemisia/Agropyron-Astragalus* associations; *Tetradymia canescens* and *Leptodactylon pungens* in the *Juniperus/Artemisia-Purshia* association.

* Annuals.

Association
Juniperus/Artemisia/Festuca
Juniperus/Artemisia/Festuca-Lupinus
Juniperus/Festuca (*Purshia* variant)
Juniperus/Artemisia/Agropyron-Chaenactis
Juniperus/Artemisia/Agropyron
Juniperus/Agropyron (*Purshia* variant)
Juniperus/Artemisia-Purshia
Juniperus/Agropyron-Festuca
Juniperus/Artemisia/Agropyron-Astragalus

Association									
Juniperus/ Artemisia/ Agropyron		*Juniperus/ Agropyron*		*Juniperus/ Artemisia-Purshia*		*Juniperus/ Agropyron-Festuca*		*Juniperus/ Artemisia/ Agropyron-Astragalus*	
Cover	Constancy	Cover	Constancy	Cover	Constancy	Cover	Constancy	Cover	Constancy
10.0	100	43.0	100	6.6	100	32.0	100	27.7	100
8.5	100	.9	100	8.2	100	3.0	100	6.7	100
			(100)						
.4	60	1.7	100	2.5	100	2.3	100		
9.2	100	5.0	100	.9	100	3.2	100	7.0	100
1.3	100	.7	100	.2	60	1.4	100	.9	100
		.3	100	.1	100	.5	100	.5	100
.3	100		50						
.1	60						20		17
.1	100	.2	100	.2	100	.1	100	.1	100
.6	100		34		20				
.1	100	.1	100	.2	100		100		[illegible]
			84	1.0	100		20		50
			17			.2	60		
.1	20	.2	100		20	3	80	.4	100
						1	80		
						1	20		
		.1	68		40	5	80		34
1.7	100	.4	100	2 7	100	1	80	.5	100
2.0	80	.2	100	.3	60	5	100		50
							20		
		.3	100		60	.3	80	.2	100
	20	.1	100	.6	100		100	1	100
1.1	100		34	.2	40	.3	60		
.6	100		34					.1	34
.1	40			.2	100		40		17
	20	.1	100	.1	100			.1	100
		.1	100	5.5	100			.3	34
		(6.7)	(100)						
		.4	84	1 5	100	.4	60	.6	50
			68	.1	100		20		17
				5	100		20		
				.1	100				
						.1	100		
			17					1	100
					80		20		
			34			.8	100		
	20				20		80		
		.1	68		20			.1	84
	20	.1	34		20				17
			17			1	20		
.1		.2		.1		.3		.3	
				.8				.2	
14.3		9.1		4.6		9.8		9.6	
9.6		1.4		16.2		4.6		7 8	
		(8.0)							

Table 5.—Mean density counts (number per 0.02 acre) and heights (feet) of shrubby and suffrutescent species in nine associations in the central Oregon juniper zone

Artemisia tridentata		*Purshia tridentata*		*Chrysothamnus nauseosus*		*Chrysothamnus viscidiflorus*		*Eriogonum sphaerocephalum*		*Eriogonum microthecum*	
Number	Height	Number	Height	Number	Height	Number	Height	Number	Height	Number	Height
104	1.29			2	1.09	55	1.24				
44	1.17			3	1.73	7	.78			4	0.69
29	1.17	4	3.26	1	2.10	10	.44	2	0.45		
(5)		(6)	(3.78)								
26	1.32	1	.90	4	.99	10	.86				
26	1.95			4	2.03						
4	1.32	2	1.93	1	1.75	8	.66	1	.60		
(3)	1.82	(7)	(2.69)								
34	1.79	13	2.49	3	1.74	17	1.40				
17	1.52			2	1.73	6	.71	17	.69	4	-
26	1.26	1	2.90			9	.89				

Juniperus/Artemisia/Festuca Association

This association occurred on northwest- to northeast-facing slopes with loamy Chestnut soils. The vegetation was relatively dense with a perennial herbaceous foliage cover of 20.5 percent (fig. 3), the greatest amount measured in any of the entities. Soil surface occupied by perennial herbs, organic matter in the A horizon, and total nitrogen in the A horizon, 7.4, 4.78, and 0.21 percent, respectively, was also greater in this unit (table 3). Bare soil surface, 22.1 percent, was less than in the other units. Although available soil moisture storage capacity in the 2- to 14-inch soil zone, 1.41 inches, was less than in some of the other units (table 3), its effectiveness was increased by loamy and clayey surface and subsoils, rockiness of the solum, and reduced insolation on the northerly aspect.

Juniperus occidentalis, *Artemisia tridentata*, and *Festuca idahoensis* were the most characteristic species of the plant community. Respectively, they provided 12.0-, 7.4-, and 10.8-percent foliage cover. *Agropyron spicatum*, the next most abundant plant, had a foliage cover value of 5.3 percent and provided a characteristic bunchgrass aspect (fig. 4). The combined foliage cover value of this species and *Festuca idahoensis* was at least 20 percent greater than for the same species in any of the other entities. *Poa secunda* achieved its maximum development is this association as compared with the other associations.

Mature plants of A. tridentata provided 7.4-percent foliage cover and attained an average maximum height of 1.29 feet. Average density of the species was 104 plants per 0.02 acre, more than double its density in other units (table 5). Density of Chrysothamnus viscidiflorus, more than 70 percent higher than in other units, was the only other primary diagnostic characteristic of the shrub stratum.

Astragalus sp. was the most abundant forb with average foliage cover of 1.4 percent. Although the 100-percent constancy of this species was the same in the *Juniperus /Artemisia/ Agropyron* association, its cover value was nearly five times greater. *Agoseris* sp. had low cover, 0.4 percent, but it was present in all stands, a characteristic exclusive to this unit.

This association occurred with only one soil, a Chestnut loam developed from rhyolitic-andesitic colluvium (series I—see Appendix 2 for soils description). Solum depth was 30 inches. The surface horizon was a loam. The relatively high organic matter content in the surface horizon imparted a very dark brown color. The surface horizon of soils in the other ecosystems were not this dark.

The heaviest part of the B horizon was clay and had strong, blocky structure, very hard when dry and firm when moist. Ordinarily, rooting depth would be restricted because of these subsoil characteristics, but in this case, 50 percent of the solum volume was occupied by large stones which allowed roots to penetrate deeper than might be expected (fig. 5).

Juniperus /Artemisia /Festuca – *Lupinus* Association

This unit occurred on north- to northeast-facing slopes with azonal soils which supported less luxuriant vegetation than the previous association. Perennial herbaceous cover was 17.0 percent as compared with 20.5 percent in the previously described unit. *Juniperus occidentalis, Artemisia tridentata*, and *Festuca idahoensis* also characterized the vegetational component of this ecosystem but differed quantitatively from the *Juniperus/Artemisia /Festuca* association. Cover of these species was 12.3, 5.1, and 10.4 percent, respectively (table 4). Cover of *A. tridentata* provided the most striking difference, nearly 30 percent less in this association. Average maximum height of mature *A. tridentata* was 1.17 feet. Density of the species was less than half the density occurring in the first described unit (table 5).

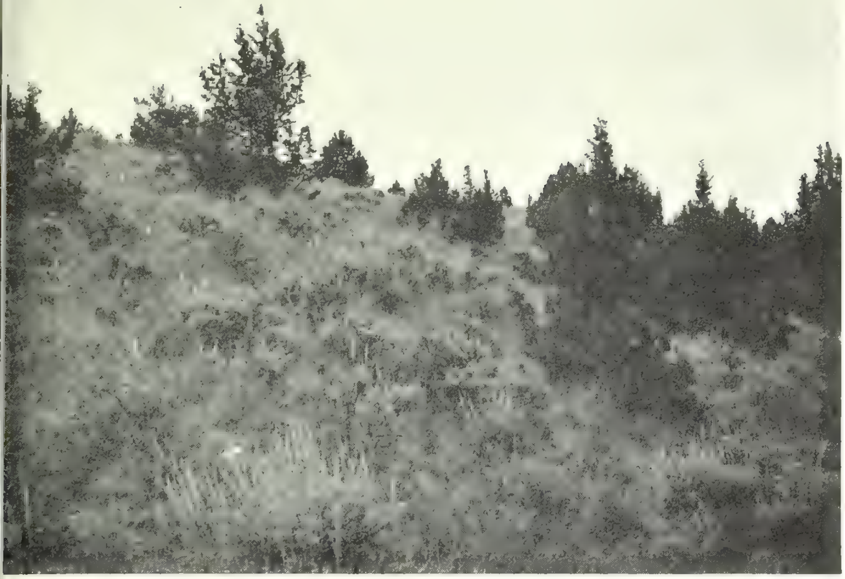


Figure 3
Stand representative of the *Juniperus/Artemisia/Festuca* association, illustrating relatively rich and dense vegetation.

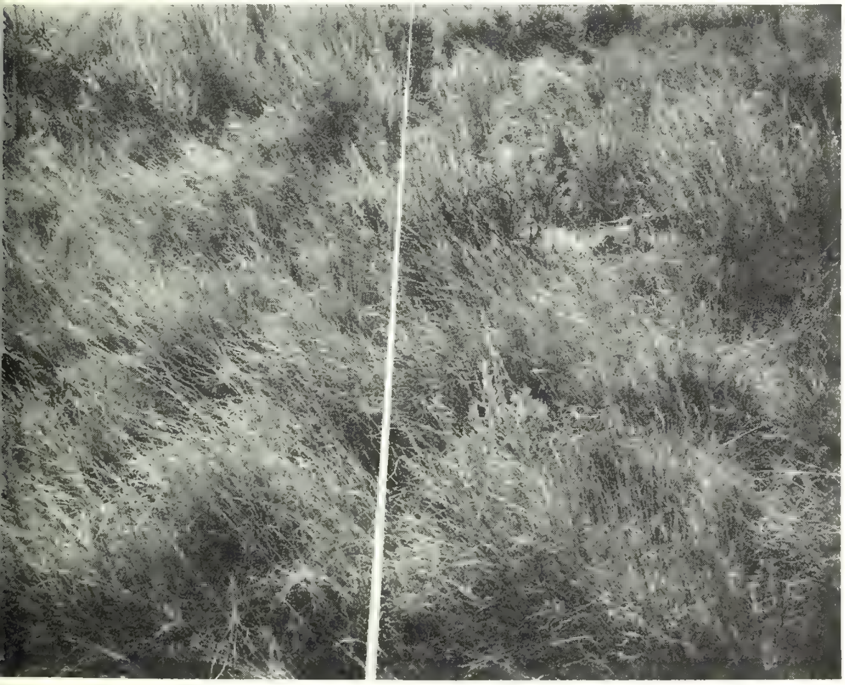


Figure 4
Detail of the understory vegetation of the *Juniperus/Artemisia/Festuca* association. The vegetational aspect is one of large, vigorous plants of *Agropyron spicatum*, although *Festuca idahoensis* is dominant on a cover basis.

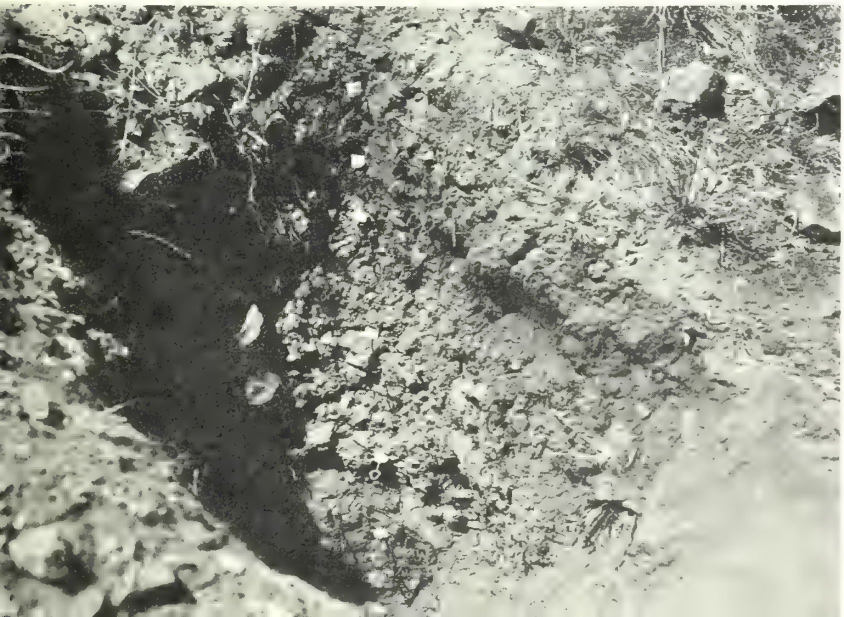


Figure 5
Profile of soil series I occurring with the *Juniperus/Artemisia/Festuca* association. Stoniness in the heavy, strongly developed B horizon allows deep root penetration. Compare with figure 18.

Juniperus occidentalis was patchy, occurring as clumps of several trees throughout the association (fig. 6). The comparative paucity of this species may be partly due to old fires. Charred tree trunks and roots were common wherever the entity was observed.

Agropyron spicatum provided only 1.5-percent cover in contrast to 5.3 percent in the *Juniperus/Artemisia/Festuca* association found on Chestnut soils. Foliage cover of *Poa secunda* was also less, 1.0 percent. *Koeleria cristata* had a cover value of 0.8 percent, a tenth greater than in any other association.

Lupinus sp. provided the most striking vegetational difference between this association and its counterpart on Chestnut soils. Here, the species was present in all stands and had a cover value of 2.3 percent but was absent in the previous association. *Phlox douglasii* and *Erigeron filifolius* provided little cover, 0.3 percent each, but they were present in all stands as compared with 40-percent constancy in the *Juniperus/Artemisia/Festuca* association.

Eriogonum microthecum was especially diagnostic of this unit. Cover and constancy of the species was 0.3 and 100 percent, respectively. The species occurred in only one other unit, the *Juniperus/Agropyron-Festuca* association, where its cover value was only 0.1 percent and constancy was only 20 percent.

The soil associated with the *Juniperus/Artemisia/Festuca-Lupinus* association was a shallow (16 inches) sandy loam Regosol overlying mixed alluvium and unconsolidated rhyolitic and andesitic stones (series II—shallow, nonstony phase). Pentagonal configurations were characteristic of the soil surface when it was dry (fig. 7). Specific reasons for the development of these configurations are not known, but they were probably associated with frost action. Some of the blocks were completely tipped over, with moss and small ephemeral plants persisting on what was once the top of the block.

The entire solum was a sandy loam with roots abundantly distributed throughout the profile (fig. 8). The available water storage capacity in the 2- to 14-inch zone was 1.98 inches, at least 20 percent more than in the same soil zone of azonal soils in other units. Total nitrogen in the A horizon was 0.10 percent. The underlying material was highly variable and loose, allowing relatively deep root penetration. Pumice sands contributed 30 percent to the solum volume.

Juniperus/ Festuca Association

This association occurred on the lower portions of northwest-facing slopes with Brown soils having loam textures. Perennial herbaceous cover was 15.1 percent. Shrub cover was scant (1.6 percent), exceeding only the *Juniperus/Agropyron* association.

Juniperus occidentalis and *Festuca idahoensis* were the most abundant species of the association. *Juniperus occidentalis* had a foliage cover value of 76.7 percent, nearly twice as much as any other association. The high cover value and the close spacing of individual trees gave the area an aspect of a relatively dense forest (fig. 9). Foliage cover of *Festuca idahoensis* was 10.8 percent, equaling that of the *Juniperus/Artemisia/Festuca* association. However, individual plants were relatively small and did not have the robust, vigorous appearance usually characteristic of the species (fig. 10).

Agropyron spicatum, *Poa secunda*, and *Koeleria cristata* had 100-percent constancies but were less characteristic perennial grasses of this association. Cover values of these species were 1.6, 0.9, and 0.3 percent, respectively. Perennial forbs were minor parts of the vegetational component of this association.

Purshia tridentata was the most diagnostic species in the shrub layer. Although cover and density values were low, 0.6 percent and 4 plants per 0.02 acre, respectively, mature plants were tall (3.26 feet). This height was exceeded only in the *Purshia* variant of the association

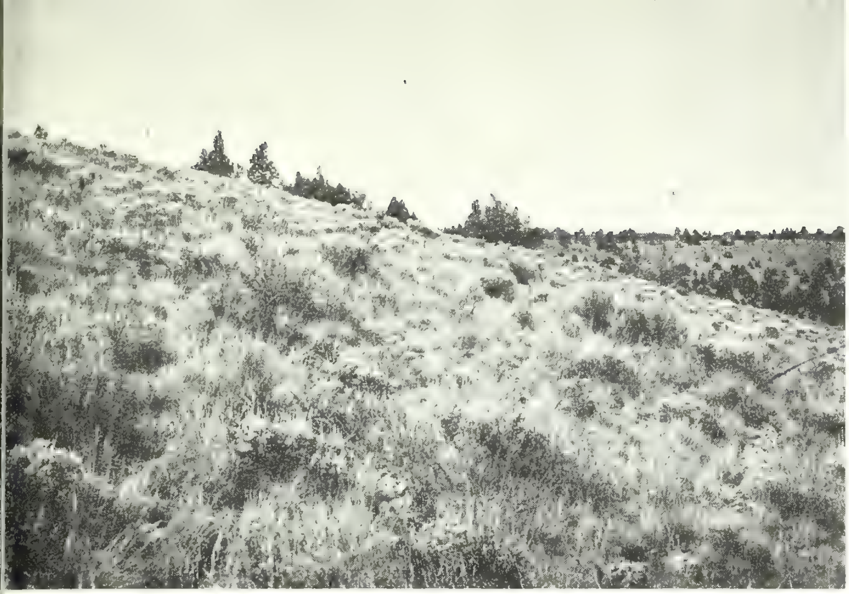


Figure 6
Stand representative of the *Juniperus / Artemisia / Festuca-Lupinus* association. The clumpiness and paucity of the *Juniperus occidentalis* component is associated with past fires.

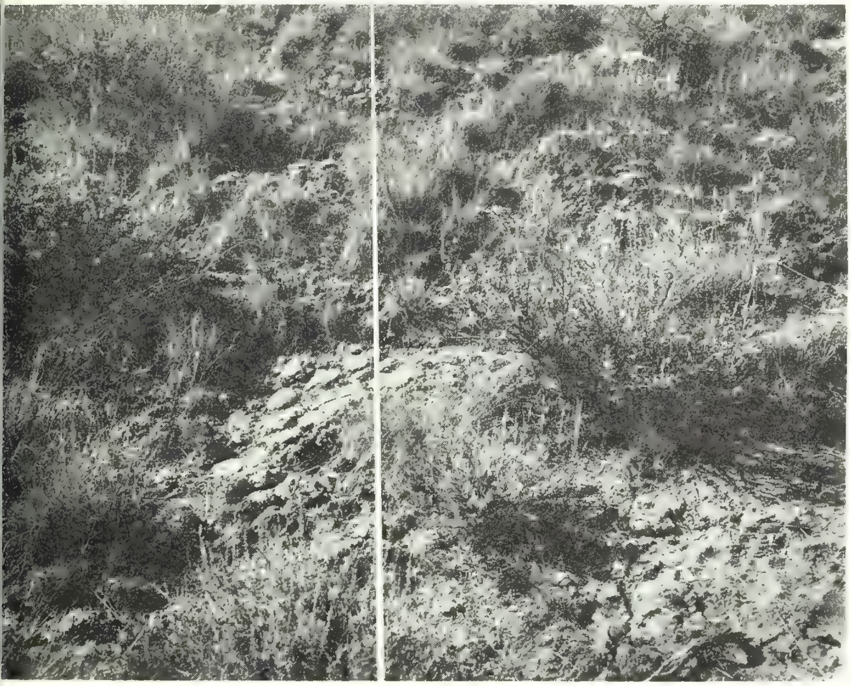


Figure 7
Detail of the soil surface and understory vegetation occurring with the *Juniperus/Artemisia/Festuca-Lupinus* association. The pentagonal configurations on the soil surface are characteristic of the soils of this unit.

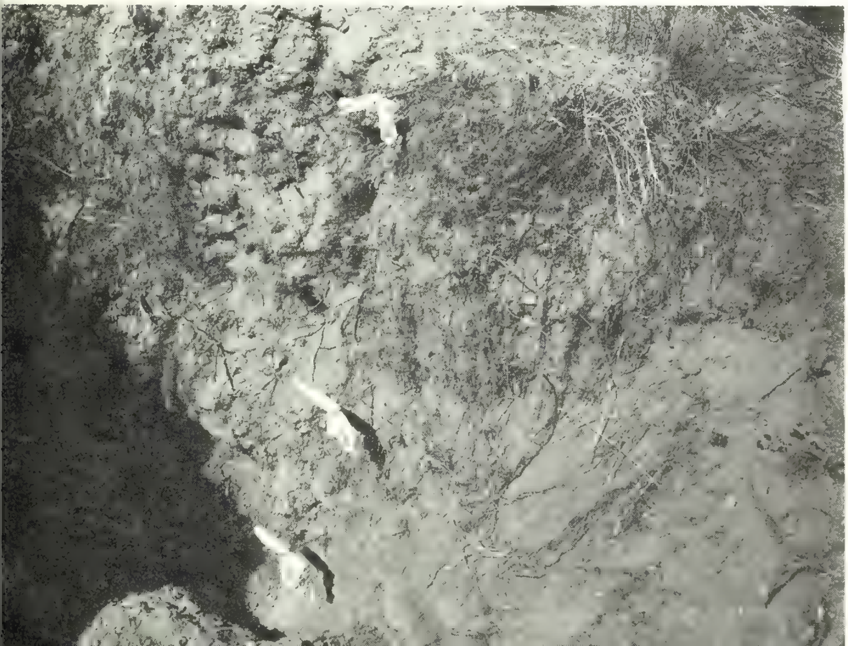


Figure 8
Soil profile of series II—shallow, nonstony phase occurring with the *Juniperus / Artemisia / Festuca-Lupinus* association. Plant roots are abundantly distributed throughout the solum. Different phases of this same series are found with three other associations, *Juniperus/Artemisia / Agropyron-Chaenactis*, *Juniperus / Artemisia-Purshia*, and *Juniperus / Agropyron-Festuca*.

being discussed (table 5). Cover and density of *Artemisia tridentata* were greater (0.9 percent and 29 plants per 0.02 acre, respectively) than *P. tridentata*, but the average maximum height of mature plants of *A tridentata* was much less (1.17 feet).

The *Juniperus/Festuca* association occurred with two soil series (series III and series IV). Both were Brown loams but had developed from different materials. Series III developed from friable, tuffaceous material. Series IV developed from aeolian sands and small, loosely packed rhyolitic and andesitic colluvial stones.

Some internal characteristics of both soils were similar. Available water storage capacity in the 2- to 14-inch soil zone was 1.81 inches. Organic matter content and total nitrogen of the A horizon was 3.91 and 0.17 percent, respectively. In contrast to the other units, these two characteristics were exceeded only in the Chestnut soil occurring with the *Juniperus/Artemisia/Festuca* association.

Subsoil textures and solum depths were different, however, between series III and series IV. Series III had a clayey subsoil not too strongly developed. The solum of this series was only 18 inches deep, but the friable underlying material allowed root penetration which compensated, to some extent, the relatively shallow depth (fig. 11). Series IV had loamy subsoils and the solum was 28 inches deep. The deeper solum and coarser subsoil texture of series IV apparently affected plant growth and distribution in a way similar to the shallow, clayey subsoil and friable parent material of series III.

Purshia variant: *Juniperus/Festuca* association.—The *Purshia* variant of the *Juniperus/Festuca* association occurred on southeasterly slopes with the very stony phase of soil series III. Vegetational characteristics were the same as the association except for cover, mature plant height, and density of *Purshia tridentata*; cover of *Festuca idahoensis*; and density of *Artemisia tridentata*.

Cover of *P. tridentata* increased from 0.6 percent in the *Juniperus/Festuca* association to 3.5 percent in its variant. Average maximum height of mature *P. tridentata* plants was 3.78 feet, approximately 0.5 foot higher than in the association. Density of the species increased from four plants to six plants per 0.02 acre, but the crowns of the individual plants in the variant were wide (fig. 12).

Cover of *Festuca idahoensis* decreased from 10.8 percent in the association to 5.3 percent in its variant. Density of *Artemisia tridentata* decreased from 29 to 5 plants per 0.02 acre but cover and mature plant height were the same. As with *Purshia tridentata*, individual plant crowns of *A. tridentata* in the variant were wide as compared with crown width of the species in the association.

Visible soil morphological characteristics of the soil occurring with the variant are the same as the soil occurring with the association except for stoniness of the solum (fig. 13). Relatively large rhyolitic and andesitic stones occupied 50 percent of the profile volume in the soil phase as compared with only 5 percent in the soil series. Other characteristics determined by laboratory analyses were quite different (table 3). Available water storage capacity in the 2- to 14-inch soil zone of the phase was 2.14 inches, 15 percent more than the same soil zone in the series was capable of storing. Organic matter and total nitrogen in the A horizon were approximately 37 and 41 percent less, respectively, in the phase as compared with the series. Regardless of these strong soil differences between the association and its variant, the stronger vegetational similarities warranted keeping the variant as a part of the association.

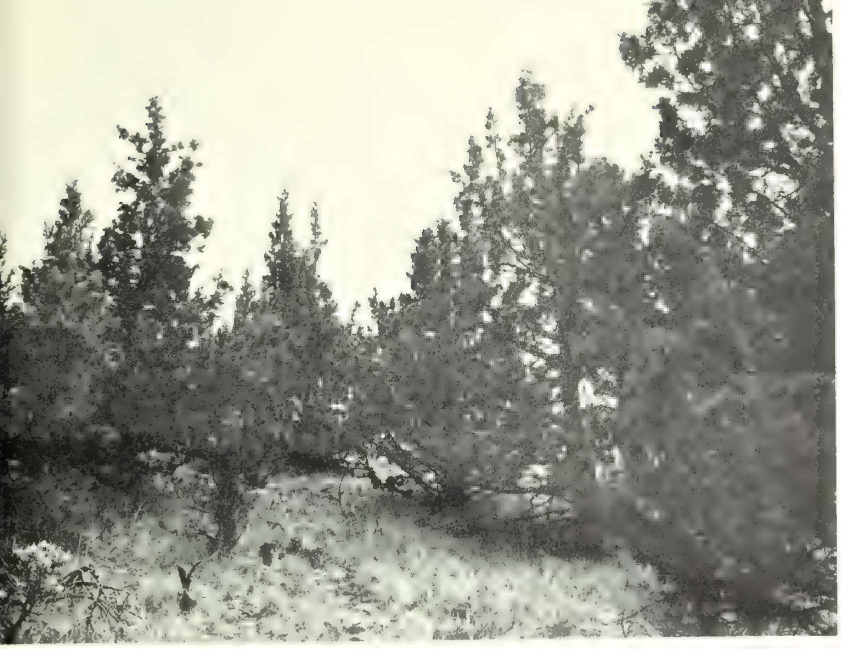


Figure 9
Stand representative of the *Juniperus/Festuca* association. This association had the highest *Juniperus occidentalis* cover in study area.

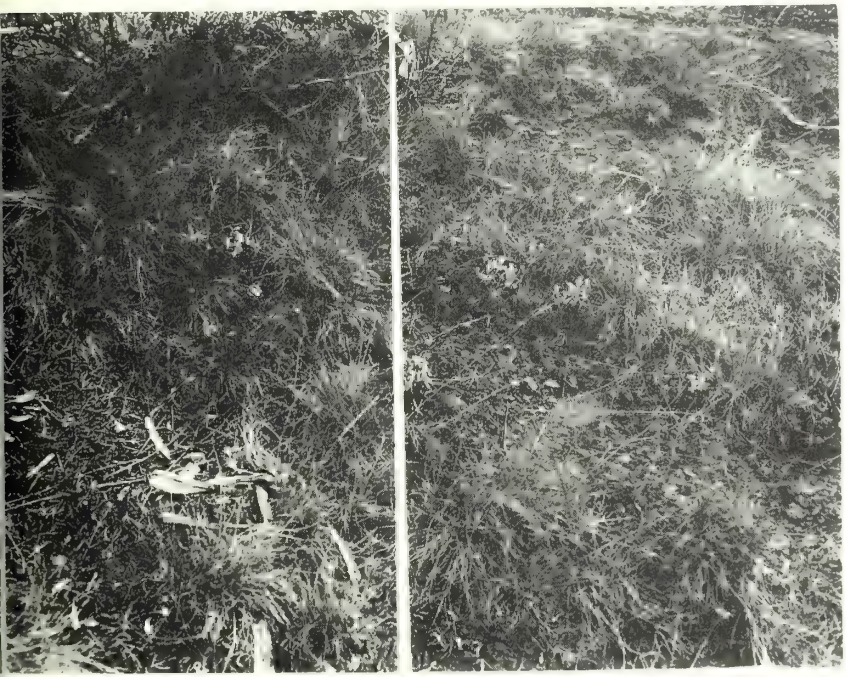


Figure 10
Detail of the understory vegetation of *Juniperus/Festuca* association. Individual plants of *Festuca idahoensis* are less robust than is characteristic for the species.

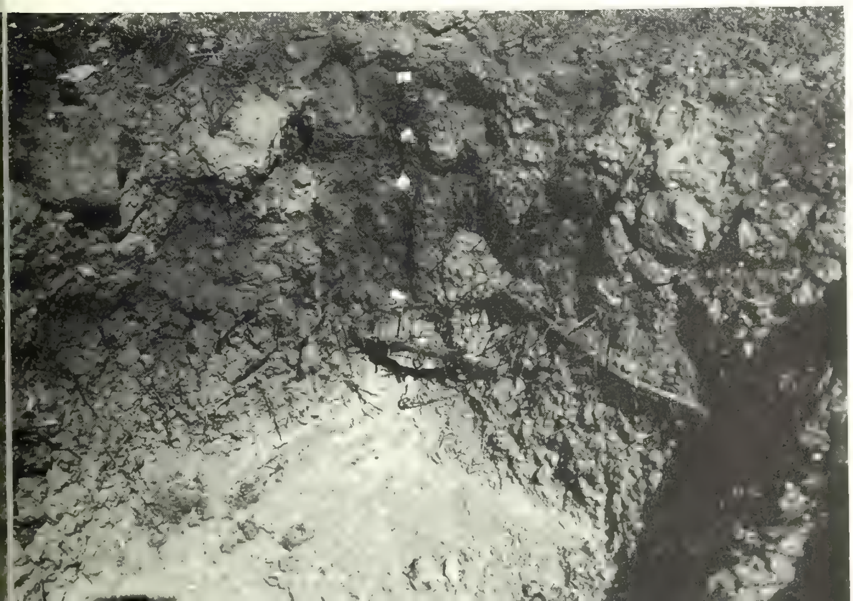


Figure 11
Profile of soil series III occurring with the *Juniperus/Festuca* association. The tuffaceous, parent material becomes friable when wet, allowing root penetration.

Juniperus/Artemisia/Agropyron-Chaenactis Association

This unit occurred on northwest- to northeast-facing slopes. The related soil was the same series and type as occurred with the *Juniperus/Artemisia/Festuca-Lupinus* association but represented a moderately deep, extremely stony phase.

Perennial herbaceous cover was more than 30 percent less than in previous units. *Agropyron spicatum* was the most abundant herbaceous species, with an average foliage cover of 3.7 percent. These characteristics indicate environmental conditions more xeric than existed in previously described units. *Juniperus occidentalis* had an average foliage cover of 46.0 percent and was fairly evenly spaced to give a savanna aspect (fig. 14). *Artemisia tridentata* was the most abundant shrub. Cover of the plant was 4.1 percent, maximum mature plant height was 1.32 feet, and plant density was 26 plants per 0.02 acre. *Chaenactis douglasii* had 100-percent constancy, an exclusive characteristic of this association.

Festuca idahoensis, Poa secunda, Koeleria cristata, and *Stipa thurberiana* had 100-percent constancies. Cover of *F. idahoensis* was only 1.9 percent, a reduction of at least 73 percent as compared with previously described units.

Some annual species provided important diagnostic characteristics in this association. *Collinsia parviflora* had 100-percent constancy and 0.6-percent cover, equaled only in the *Juniperus/Artemisia/Festuca* association. *Linanthus harknessii* had 0.2-percent cover, greater than in any of the other units. *Bromus tectorum* had an average cover of 1.7 percent, exceeded only in the *Juniperus/Artemisia-Purshia* association.

Shrubs other than *Artemisia tridentata* had little value for characterizing this association on the basis of dominance or constancy if the species were considered individually. *Chrysothamnus nauseosus, Purshia tridentata,* and *Chrysothamnus viscidiflorus* had constancy ratings of only 60 percent each and cover values of 0.2, 0.1, and 0.4 percent, respectively. The most abundant of these three species was *C. viscidiflorus*, with 10 plants per 0.02 acre. Mature plants of *C. nauseosus* were the tallest of these species, 0.99 foot. However, the characteristic relationships among these species, as compared with the same among species relationships in other entities, provided diagnostic features specific to this ecological unit. None of the other associations had even similar alliances among these species.

The soil occurring with this association was a moderately deep (26 inches), sandy loam Regosol, overlying fractured basalt bedrock or closely packed basalt stones (series II—moderately deep, extremely stony phase). It differed visually from the soil occurring with the *Juniperus/Artemisia/Festuca-Lupinus* association in solum depth, solum stoniness, and nature of the underlying material. The solum of the soil component of the *Juniperus/Artemisia/Agropyron-Chaenactis* association was 10 inches deeper and contained 50 percent more stones. Only 10 percent of the underlying material in this soil was capable of supplying moisture and available nutrients to plants as compared with 50 percent of the same material in the soil supporting the *Juniperus/Artemisia/Festuca-Lupinus* association.

Roots in this soil were abundantly distributed throughout the profile (fig. 8). Available water storage capacity in the 2- to 14-inch zone was 0.87 inch, less than half the capacity of the shallow, nonstony phase supporting the *Juniperus/Artemisia/Festuca-Lupinus* association. This was primarily the result of the greater volume of stones in the solum. Organic matter content and total nitrogen of the A horizon were 1.59 and 0.08 percent, respectively, slightly less than the shallow nonstony phase. The soil surface was 52.3-percent bare and had 5.2 percent of its area occupied by root crowns of herbaceous perennials (fig. 15).

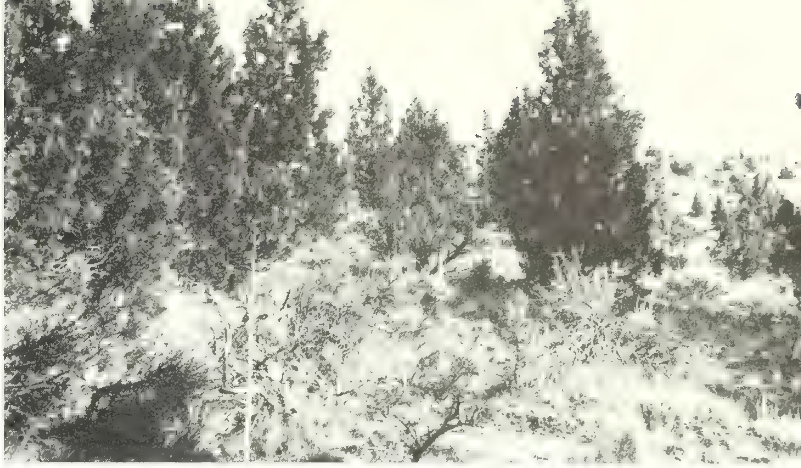


Figure 12
Stand representative of the *Purshia* variant: *Juniperus/Festuca* association. Density of *Purshia tridentata* is low, but individual plant crowns are wide. The species is in the center of the picture.

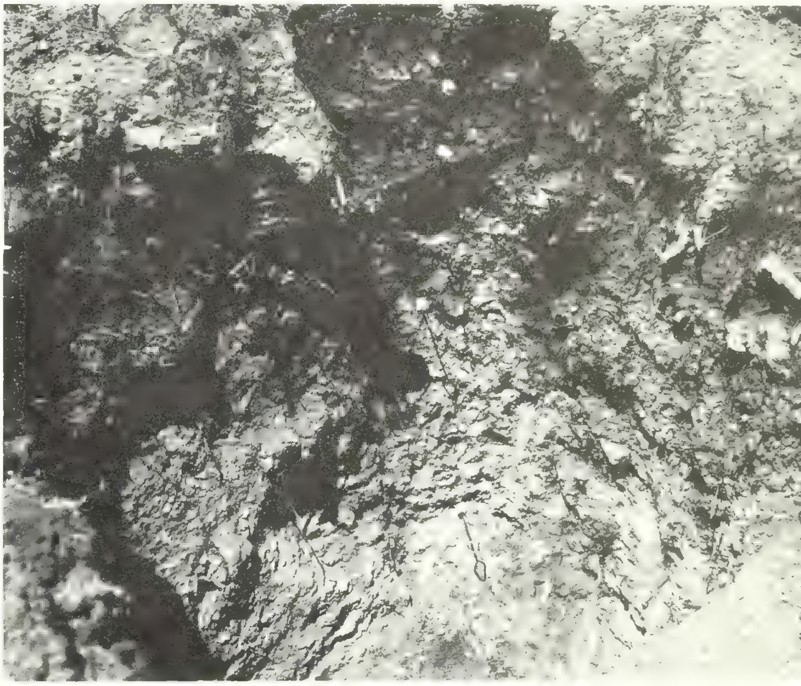


Figure 13
Soil profile of series III—very stony phase, supporting the *Purshia* variant: *Juniperus/Festuca* association. Rhyolitic and andesitic stones occupy 50 percent of the profile volume.

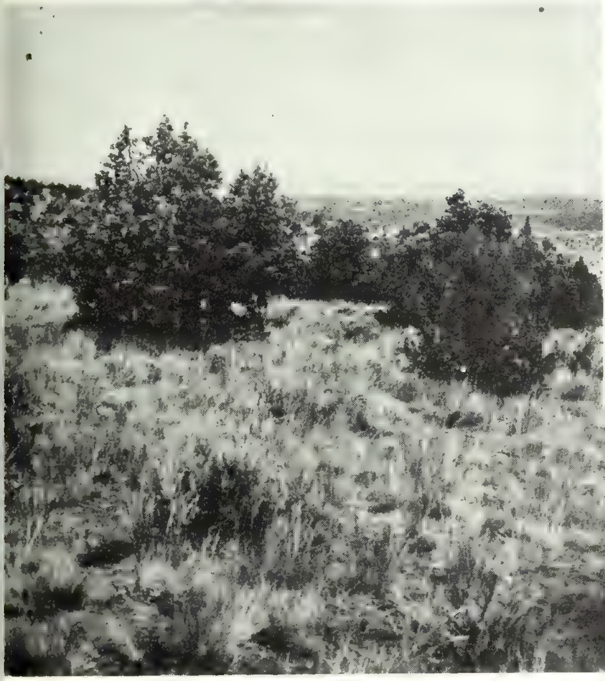


Figure 14
Stand representative of the *Juniperus/Artemisia/Agropyron-Chaenactis* association. *Juniperus occidentalis* is fairly evenly spaced, providing the characteristic savanna aspect of the juniper zone.

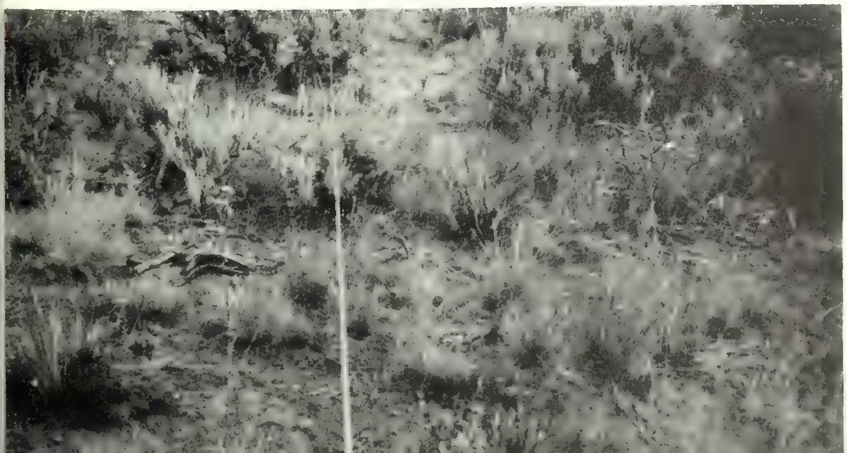


Figure 15
Detail of the soil surface and understory vegetation related to *Juniperus/Artemisia/Agropyron-Chaenactis* association. Approximately 52.3 percent of the soil surface is bare.

Juniperus/Artemisia/Agropyron Association

This association occurred on undulating uplands with strongly developed Brown soils. *Juniperus occidentalis*, *Artemisia tridentata*, and *Agropyron spicatum* characterized the vegetational component of this association (fig. 16). Cover of *J. occidentalis* averaged 10 percent. However, the trees were unevenly distributed, occurring in small clumps throughout the area. This situation was similar to the grouping of the trees in the *Juniperus/Artemisia/Festuca-Lupinus* association. In both cases, wildfire appears to have been a major factor determining tree survival and distribution. Charred stumps and logs on the surface and roots in the soil were fairly common.

Artemisia tridentata attained maximum stature in this unit as compared with the other classified units. Average maximum height of mature plants was 1.95 feet. Foliage cover of the species was 8.5 percent. Both of these characteristics were at least 10 percent greater than in any of the other associations. *Chrysothamnus nauseosus* was the only other shrub measured in the association. The 1.1-percent cover of the species was at least 70 percent greater than in other associations.

Agropyron spicatum also reached maximum development in this unit as compared with the other associations. Cover of the species was 9.2 percent, nearly a fourth more than in any other unit. Most of the plants were robust and widely spaced, prominent characteristics of the association (fig. 17).

Stipa thurberiana was the next most abundant herb in the *Juniperus/Artemisia/Agropyron* association. Although constancy of the species (80 percent) was exceeded in other units, its cover value (2 percent) was at least 35 percent greater than in other units. *Poa secunda*, *Festuca idahoensis*, and *Sitanion hystrix* were the only other perennial grasses encountered in the sample plots. Cover of these species was 1.3, 0.4, and 0.1 percent, respectively. *F. idahoensis* was found mostly in the deep shade of shrubs or trees.

In general, there was a paucity of perennial forbs. *Lomatium triternatum* was the most prevalent with 0.6-percent cover. Including this species, only eight forbs were identifiable when the association was examined.

An annual grass, *Bromus tectorum*, was fairly abundant. It occurred throughout the area with 1.7-percent cover. *Festuca octoflora* had a cover of 0.6 percent and constancy of 100 percent, considerably more than in any of the other associations. Other annuals were present but not as characteristic as these species.

Two soil series occurred with the *Juniperus/-Artemisia/Agropyron* association (series V and series VI). Both were strongly developed Brown loams but had formed from different parent materials. Series V developed from river- and lake-laid sediments; series VI developed from relatively loose loess and very fine sands. The parent material of both soils contained numerous, partially decomposed, small basalt fragments and was 26 and 13 inches, respectively, below the surface of the two soils. Discontinuous caliches occurred in the lower B horizons of the two soils. Small stones occupied 5 percent of the volume of the solum of both soils.

The primary internal characteristics visibly different between these series were position, thickness, and texture of the heaviest portion of the B horizon. In series V, this soil layer began approximately 15 inches below the soil surface, was 8 inches thick, and had clay texture. The same horizon of series VI started at an average of 8 inches below the soil surface, was 2 inches thick, and had clay loam texture.

This heavy subsoil horizon of these soils was similar to the same horizon in series I of the *Juniperus/Artemisia/Festuca* association. In all these soils, this horizon was strongly structured, very hard, and firm. However, the paucity of stones in the soils of the *Juniperus/ Artemisia/ Agropyron* association, together with the textural, structural, and consistency characteristics, restricted root penetration (fig. 18). In series

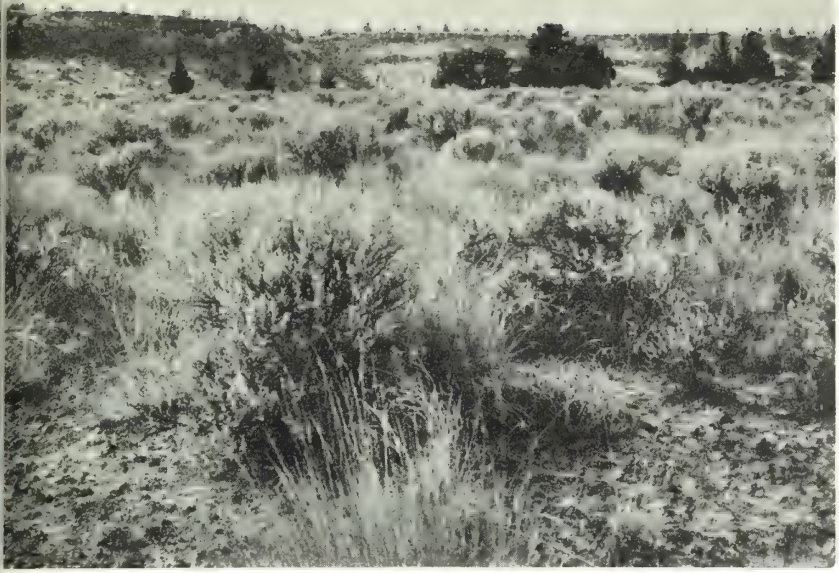


Figure 16
Stand representative of the *Juniperus / Artemisia / Agropyron* association characterized by clumps of *Juniperus occidentalis* and maximum development of *Artemisia tridentata* and *Agropyron spicatum.*

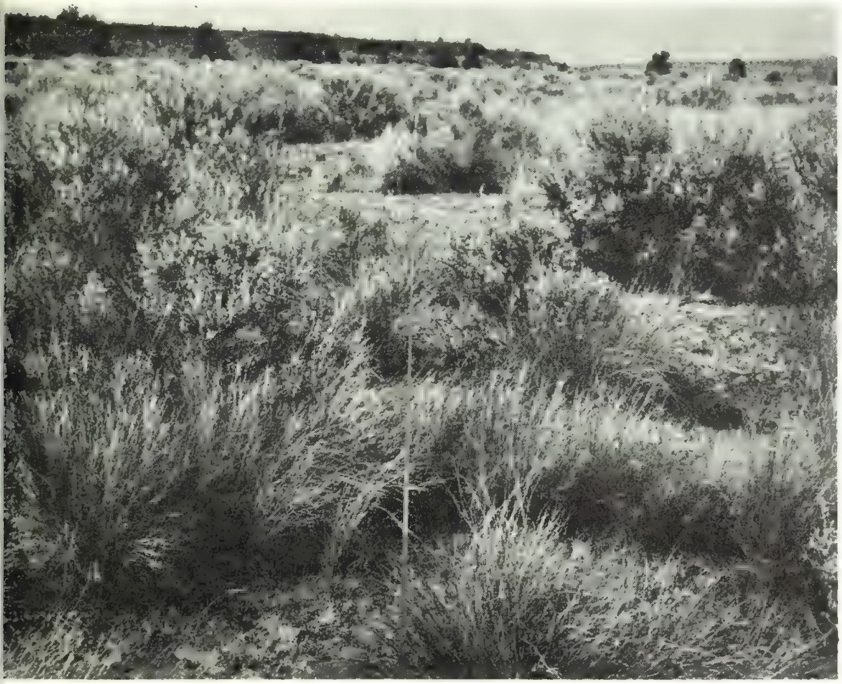


Figure 17
Detail of the herbaceous and shrubby components of the *Juniperus / Artemisia / Agropyron* association. Wide spacing and high cover of *Agropyron spicatum* are diagnostic features of the area.

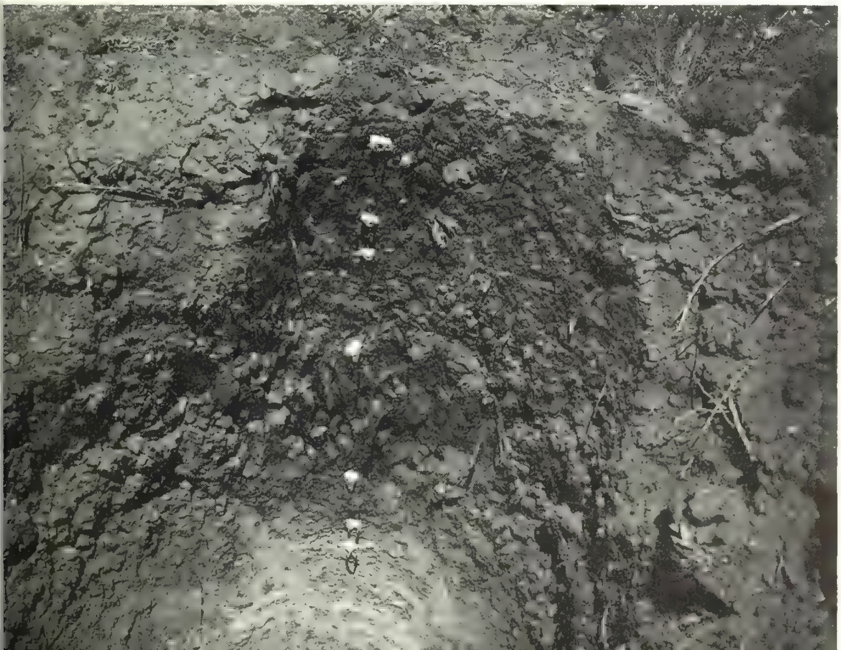


Figure 18
Soil profile of series V supporting the *Juniperus/Artemisia/ Agropyron* association. The strongly structured, very hard, and firm B horizon restricts root penetration. Compare with figure 5.

V no roots were found below the heaviest subsoil horizon. The thinness and slightly coarser texture of this horizon in series VI allowed some roots to penetrate to deeper soil material. In series I, roots were common to abundant throughout the solum.

Other internal characteristics of series V and series VI were the same. Available water storage capacity in the 2- to 14-inch zone was 2.31 inches. This quantity was greater than in any of the other units but was less effective because of the topographic position of this unit and subsoil characteristics. Organic matter and total nitrogen of the A horizon were 1.50 and 0.08 percent, respectively. These quantities were less than occurred in any of the other zonal soils which occurred with the *Juniperus/Artemisia/Festuca, Juniperus/Festuca, Juniperus/Agropyron,* and *Juniperus/Artemisia/Agropyron-Astragalus* associations.

Juniperus/ Agropyron Association

This association occurs on east- to northeast-facing slopes with Brown sandy clay loam soils. The shrubby layer was nearly absent in this unit (fig. 19). Density of *Artemisia tridentata* was only four plants per 0.02 acre, the least number counted in any of the units (table 5). The 0.9-percent cover of the species provided 64 percent of the total 1.4-percent shrub cover. This total shrub cover value was less than in all other associations.

An unusual relationship occurred between *Agropyron spicatum* and *Festuca idahoensis*. Comparatively, *A. spicatum* was more abundant on drier sites such as south- or west-facing slopes, but *F. idahoensis* was more abundant on the more mesic sites of north- and east-facing slopes. In this association, however, *A. spicatum,* with 5.0-percent cover, dominated the herbaceous layer and *F. idahoensis* had only one-third as much cover and was a relatively minor species (fig. 20). The abundance of stones on and in the soil, as it affected soil moisture, temperature, and plant-supporting area of the association, probably contributed to this relationship.

Juniperus occidentalis had a cover of 43.0 percent. The trees were fairly evenly distributed and provided an aspect similar to the *Juniperus/Artemisia/Agropyron-Chaenactis* association.

Few perennial forbs occurred in this association and those present were in limited amounts. *Poa secunda, Koeleria cristata, Achillea millefolium, Phlox douglasii, Stipa thurberiana, Astragalus* sp., and *Erigeron linearis* each had 100-percent constancy rating. However, the combined cover of all these species was only 2.0 percent which consists mostly of *P. secunda* with 0.7-percent cover.

Associated with the *Juniperus/Agropyron* association were two soil series and a phase of one of these series (series VII, series VIII, and series VII—shallow phase). Series VII and its shallow phase occurred with the association. Series VIII occurred with the *Purshia* variant subsequently discussed.

Series VII was a sandy clay loam developed from a relatively thin layer of rhyolitic-andesitic colluvium overlying indurate tuffaceous material (fig. 21). The underlying stratum was unrelated to the soil but affected plant growth by restricting root penetration.

With the exception of solum depth, which changes horizon thickness, characteristics of the series and its stony phase were very similar. Solum depth of the series was 40 inches and of the phase was 20 inches. The heaviest part of the subsoil was a clay loam with moderate to strong prismatic and blocky structure, very hard when dry, becoming friable when moist. The moist friability of this part of the soil and the high stone content (40 percent) permitted good root penetration. This was in contrast to the subsoil conditions in series V of the *Juniperus / Artemisia/Agropyron* association. In this soil, the moist consistency of the heaviest part of the subsoil was firm, which mechanically restricted root penetration.

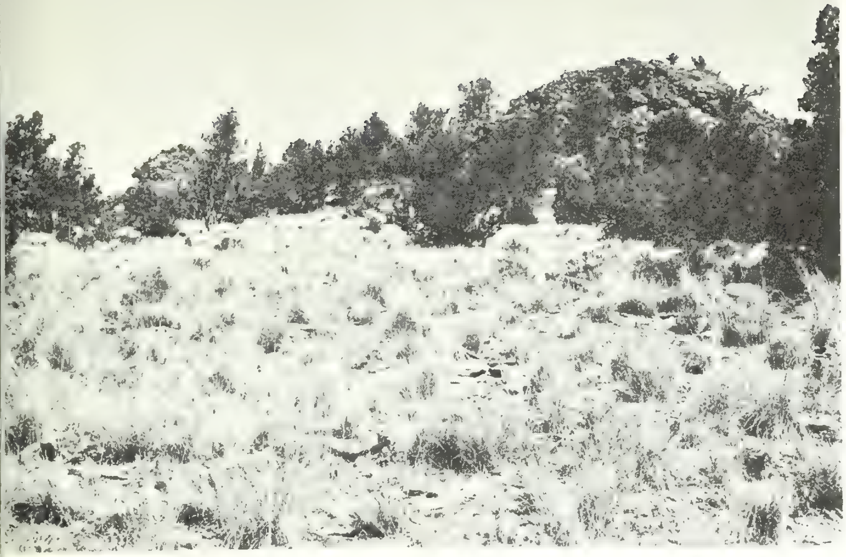


Figure 19
Stand representative of the *Juniperus/Agropyron* association. The shrub layer was nearly absent in this unit.

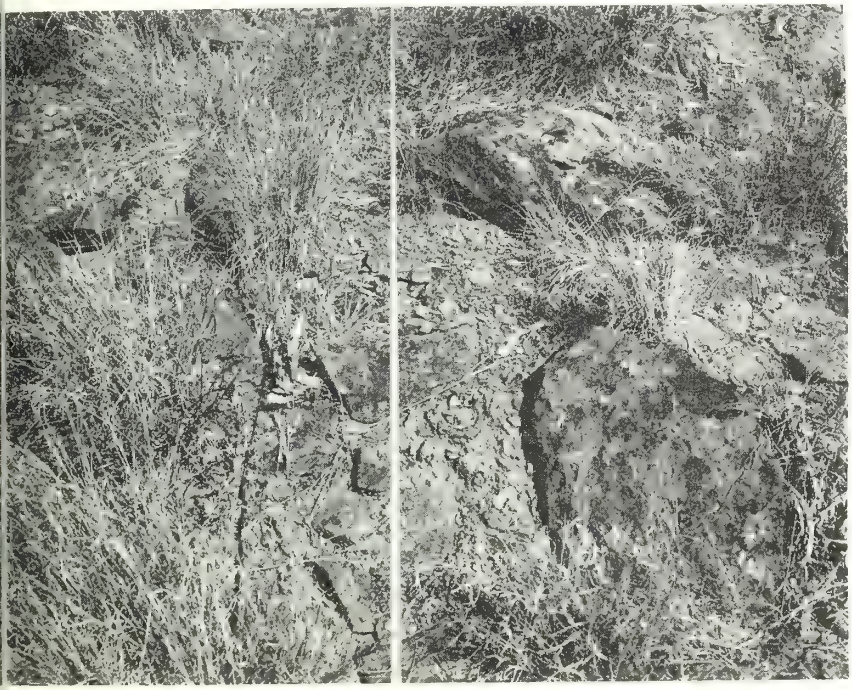


Figure 20
Detail of the soil surface and herbaceous vegetation related to *Juniperus/Agropyron* association. *Agropyron spicatum* dominates the herbaceous layer of this north-slope area. The many large stones on the soil surface are specific to this unit.

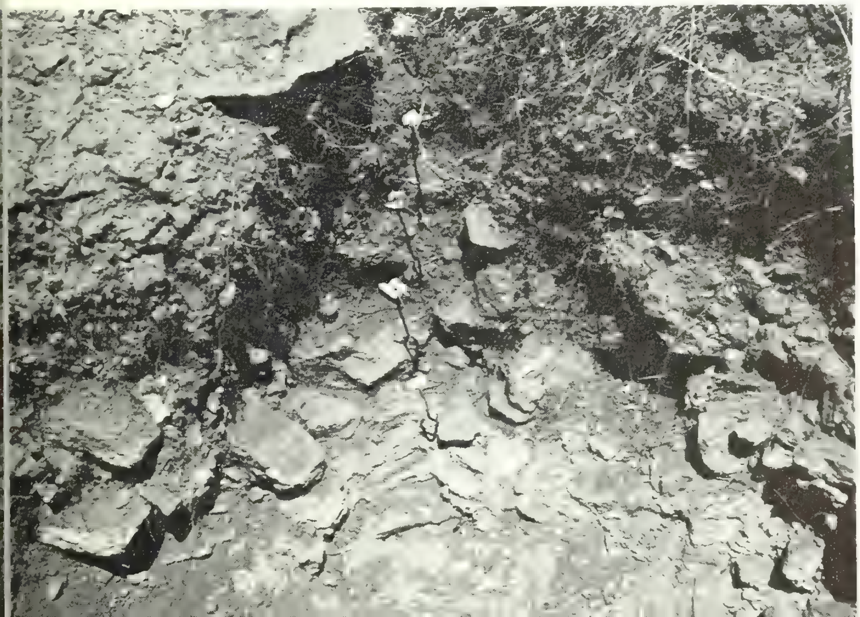


Figure 21
Soil profile of series VII occurring with the *Juniperus/Agropyron* association. The indurate material underlying the soil stops root growth and penetration.

The soil surface in the *Juniperus/Agropyron* association was 51.1-percent bare, the highest percentage of any of the zonal soils. Root crowns of perennial herbs occupied 3.2 percent of the soil surface, less than any of the other zonal soils. Available water storage capacity in the 2- to 14-inch soil zone was 1.34 inches. Organic matter content and total nitrogen of the A horizon were 2.12 and 0.10 percent, respectively.

Purshia variant: *Juniperus/Agropyron* association.—The *Purshia* variant of the *Juniperus/Agropyron* association occurred on southeasterly slopes with a Brown loam soil (series VIII). Vegetational characteristics of the association and the variant were the same, except for the strong development of *Purshia tridentata* in the variant (fig. 22). Here, the species attained the maximum cover of any of the units measured (6.7 percent). This was almost twice the cover value of the species in the *Purshia* variant of the *Juniperus/Festuca* association and nearly 20 percent more than in any of the associations. Density of *P. tridentata* was seven plants per 0.02 acre. Average maximum height of mature plants was 2.69 feet, approximately 1 foot shorter than in the *Purshia* variant of the *Juniperus/Festuca* association.

Soil factors and slope aspect seemed to have primary influence on the development of *P. tridentata* in the *Purshia* variant of the *Juniperus/Agropyron* association. The soil was a relatively shallow (20 inches) loam developed from rhyolitic-andesitic colluvium. The stony parent material was loose and had sandy clay material between the large stones. The densest portion of the subsoil was a strongly structured, hard, and firm clay. Relatively large stones, comprising 40 percent of the solum, modified the strongly developed clayey subsoil and allowed deeper root penetration than existed in series VII associated with the *Juniperus/Agropyron* association (fig. 23).

Even though the association and its variant occurred with different soil classes and slopes, similar vegetational characteristics, other than *P. tridentata*, and similarity of some soil characteristics warranted classifying the variant as a part of the association.

Juniperus/Artemisia-Purshia Association

The vegetational component of this association was characterized principally by a conspicuous shrub layer (fig. 24). Total shrub cover in the unit (16.2 percent) was almost twice as much as the amount of shrub cover in other units. *Artemisia tridentata* and *Purshia tridentata* shared importance with 8.2- and 5.5-percent cover, respectively. Mature plant height of *A. tridentata* averaged 1.79 feet. These characteristics of *A. tridentata* were exceeded only in the *Juniperus/Artemisia/Agropyron* association where it attained its maximum stature in the units measured. Density of *P. tridentata*, 13 plants per 0.02 acre, was nearly twice as great as its density in the variants of the *Juniperus/Festuca* and *Juniperus/Agropyron* associations. Average maximum height of mature plants was 2.49 feet.

Herbaceous annuals were diagnostic of this association although they were inconspicuous in the general aspect. *Collinsia parviflora*, *Gayophytum lasiospermum*, *Bromus tectorum*, *Cryptantha ambigua*, *Collomia grandiflora*, *Mentzelia albicaulis*, and *Montia perfoliata* all had a constancy of 100 percent. Total cover of these annual species was 11 percent greater than total cover of perennial herbs. *Bromus tectorum* attained its maximum cover, 2.7 percent, in this association. Cover of *G. lasiospermum* (1 percent), *C. ambigua* (0.6 percent), *M. albicaulis* (0.5 percent), and *C. grandiflora* (0.1 percent), were also greater here than in any of the other units.

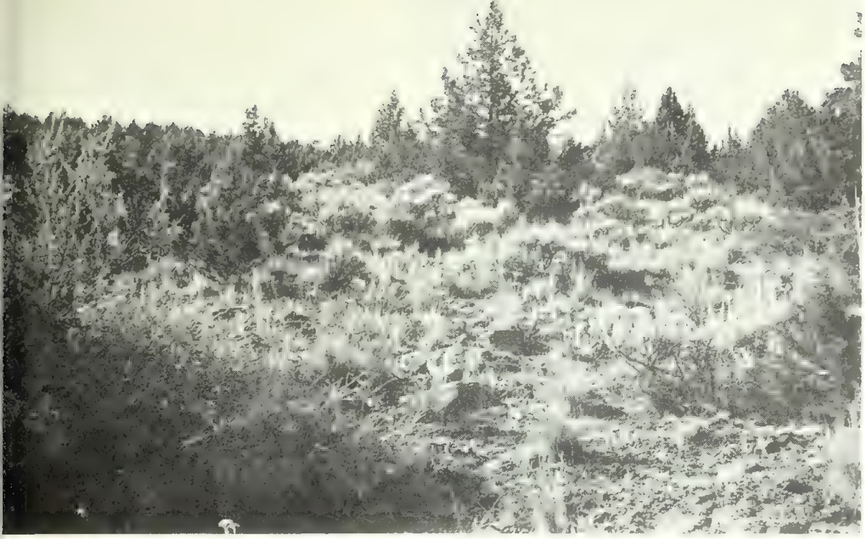


Figure 22
Stand representative of the *Purshia* variant: *Juniperus/Agropyron* association. *Purshia tridentata* attained its maximum cover on this site as compared with the other units.

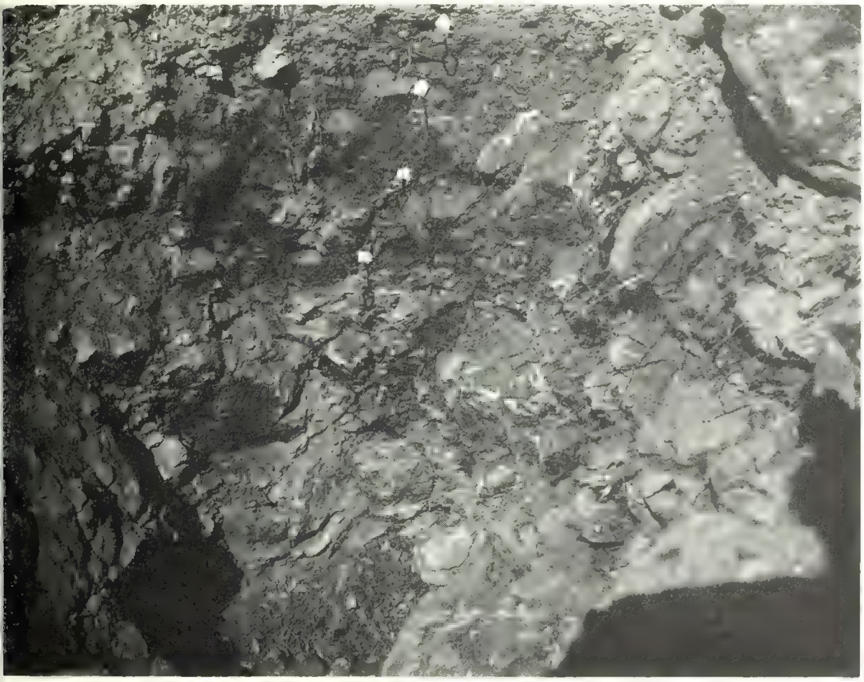


Figure 23
Soil profile of series VIII supporting the *Purshia* variant: *Juniperus / Agropyron* association. The stony solum and loose parent material allow deep penetration of *Purshia tridentata* roots.

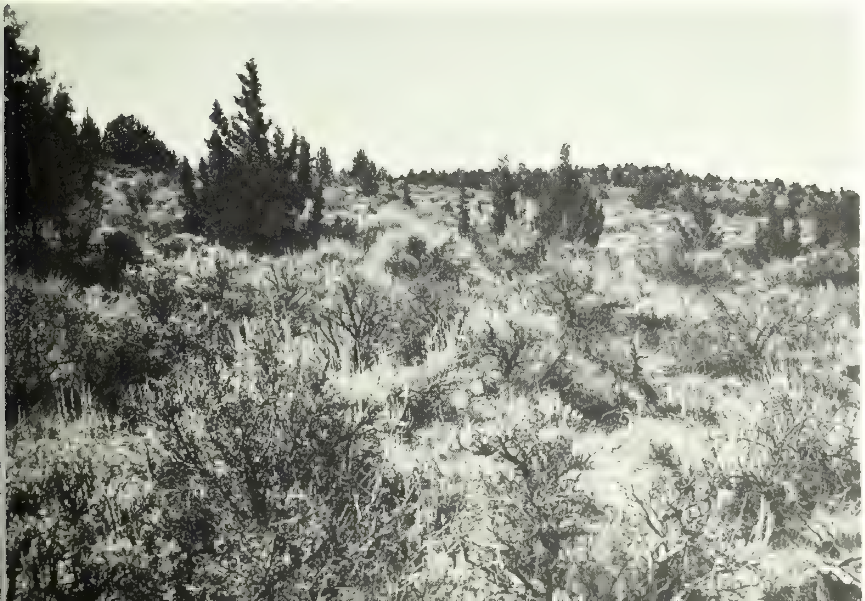


Figure 24
Stand representative of the *Juniperus/Artemisia-Purshia* association. *Artemisia tridentata* and *Purshia tridentata* share dominance in the shrub layer of this entity.

Sitanion hystrix attained maximum development in this association as compared with the others, with a constancy of 100 percent and a cover of 0.2 percent. It occurred in five other units but had minor constancy and cover characteristics. *Stipa comata* was also diagnostic with a constancy of 80 percent. The species occurred in only one other unit, the *Juniperus/ Agropyron-Festuca* association, but had a constancy of only 20 percent.

Generally, herbaceous perennials were widely spaced and provided minor characterization value if considered individually. They were found mostly under the protective shade of shrubs (fig. 25). However, total cover of perennial herbs, 4.6 percent, was less than half the total perennial herb cover of any of the other associations.

The 6.6-percent cover of *Juniperus occidentalis* was another major diagnostic feature of this association. This cover value of the species was the least amount occurring in any of the units.

The soil occurring with the *Juniperus/Artemisia-Purshia* association was a deep, nonstony, sandy loam Regosol overlying a stony, loamy B2 horizon (series II—deep, nonstony phase). It differed principally from the previously described Regosols occurring with the *Juniperus/ Artemisia/Festuca-Lupinus* and the *Juniperus/ Artemisia/Agropyron-Chaenactis* associations in depth to the underlying material (45 inches), nature of the underlying material, and nonstoniness.

The entire solum was a structureless sandy loam (fig. 8). Internal drainage was very rapid, indicated by the mildly alkaline reaction (pH 7.5) of the deepest sandy material. Calcareous deposits, very common in soils of low-precipitation regions, were not found in this soil except in the buried horizon. These factors indicated a droughty soil environment, even though available water storage capacity in the 2- to 14-inch soil zone was 1.54 inches, a greater amount than some of the other soils (table 4). Most plant roots were concentrated in the upper 16 inches of the soil. Some roots, particularly large ones of the shrubs and trees, extended into the buried soil.

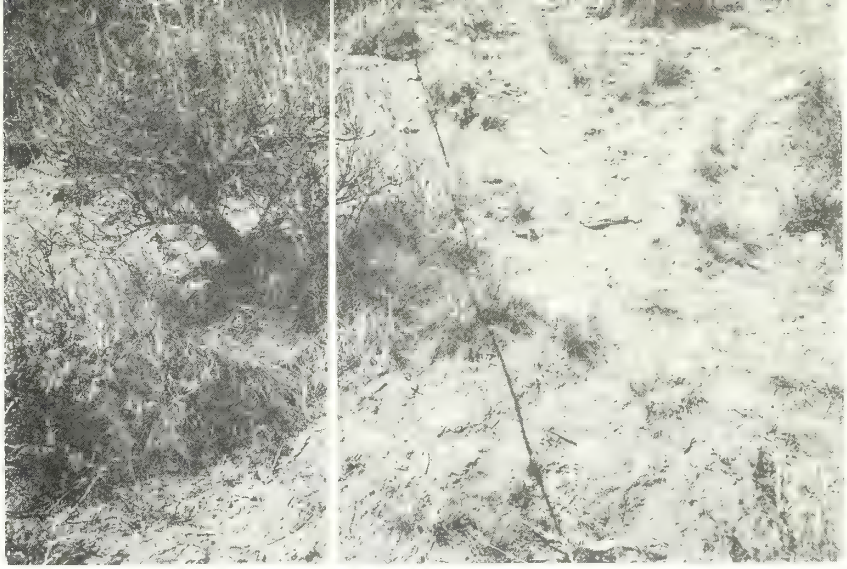
The amount of bare soil surface (55 percent) was more and the surface area occupied by root crowns of herbaceous perennials (3.1 percent) was less than occurred with any of the other azonal soils. The surface soil was extremely loose, requiring a minimum of traffic to create excessive disturbance (fig. 25). The comparatively low quantities of organic matter and total nitrogen in the A horizon, 1.05 and 0.06 percent, respectively, were the least amounts measured in any of the units.

Juniperus/Agropyron-Festuca Association

This association was limited to east slopes and was characterized by large, mature *Juniperus occidentalis*, codominant status of *Agropyron spicatum* and *Festuca idahoensis* in the herbaceous layer, and specificity of *Eriogonum ochrocephalum* and *Eriogonum sphaerocephalum* (fig. 26).

Juniperus occidentalis had a cover of 32 percent, the second largest amount of the four associations on azonal soils. Cover of *A. spicatum* and *F. idahoensis* was 3.2 and 2.3 percent, respectively. Both plants had typical bunchgrass appearances and were spatially separated by considerable bare soil surface (fig. 27). The two species of *Eriogonum* had constancies of 100 percent, much greater than in the other associations where they occur. Cover of *E. sphaerocephalum* was 0.8 percent. Density of this suffrutescent species was 17 plants per 0.02 acre. The average maximum height of the mature plants was 0.69 foot. This species also occurred in the *Juniperus/Festuca* and *Juniperus/ Agropyron* associations but in minute quantities. Cover of *E. ochrocephalum* was low, 0.1 percent. This species was present in three other units, the *Juniperus/Artemisia/Festuca-Lupinus*, the *Juniperus/Festuca*, and the *Juniperus/Artemisia/ Agropyron-Chaenactis* associations, but did not occur on the observation plots.

Figure 25
Ground detail of the *Juniperus/Artemisia-Purshia* association. Perennial herbs are characteristically grouped under the protective shade of shrubs.



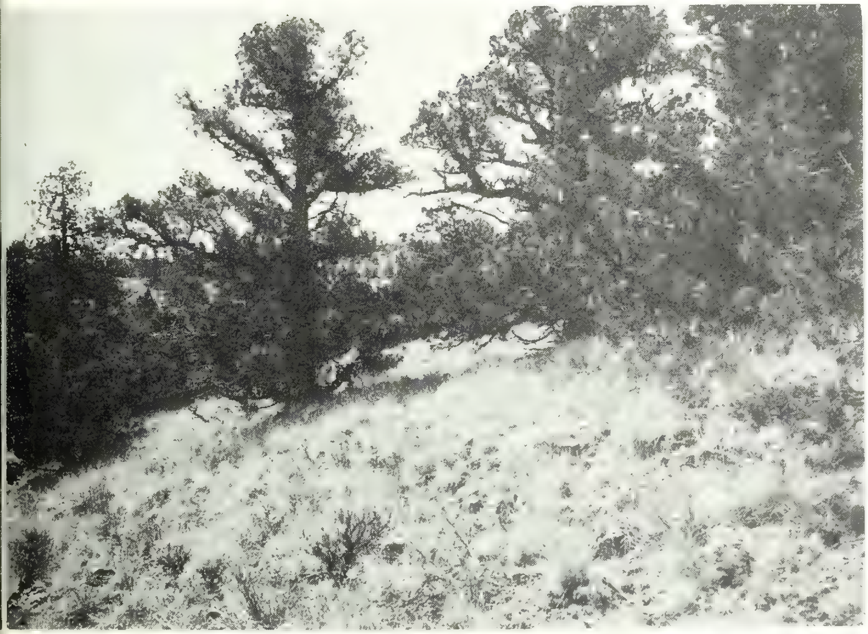


Figure 26
Stand representative of the *Juniperus / Agropyron-Festuca* association. Large, mature *Juniperus occidentalis* and the codominant status of *Agropyron spicatum* and *Festuca idahoensis* in the herbaceous layer characterize this entity.

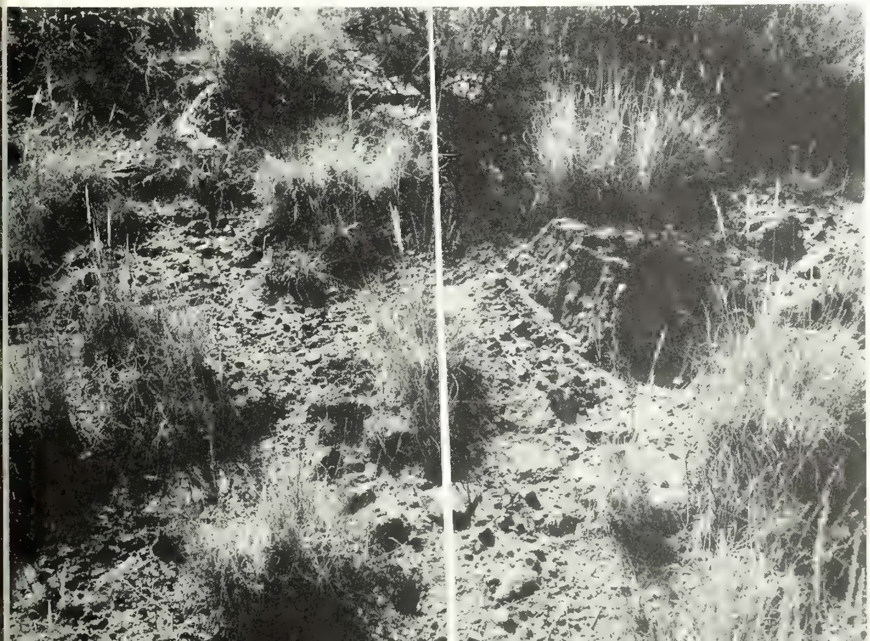


Figure 27
Ground detail of the *Juniperus/ Agropyron-Festuca* association. *Agropyron spicatum* and *Festuca idahoensis* share dominance in the herbaceous stratum. The conspicuous seedheads are *Koeleria cristata*. Several species occupied the same small space on the soil surface.

Most of the 4.6-percent shrub cover in this association was composed of *Artemisia tridentata* (3 percent). This cover value of the species was the least amount measured in any of the associations found with azonal soils.

Seedheads of *Koeleria cristata* provided a characteristic aspect in the herb layer when the association was studied (fig. 27). They were inconspicuous in other units even though cover of the species was often equaled or exceeded. *Poa secunda* had a relatively large cover value (1.4 percent) and was exceeded only in the *Juniperus / Artemisia / Festuca* association.

The soil supporting the vegetation of this entity was a moderately deep (23 inches), very stony, sandy loam Regosol overlying closely packed, cemented, rhyolitic-andesitic colluvium (series II—moderately deep, very stony phase). The primary difference between this soil and others of the same series as it influenced plant growth was the cementation of the underlying stratum. This stratum in the azonal soils occurring with the *Juniperus / Artemisia / Festuca-Lupinus*, the *Juniperus / Artemisia / Agropyron-Chaenactis*, and the *Juniperus / Artemisia-Purshia* associations was readily penetrable to plant roots.

The entire solum was a structureless sandy loam (fig. 8) and filled to approximately 35 percent with large stones. As a result, available water storage capacity in the 2- to 14-inch soil zone was 0.97 inch. Plant roots were mostly in the top 16 inches of the solum, although a few larger ones trailed on top of the cemented material and occasionally penetrated a soft spot. Organic matter and total nitrogen in the A horizon were 1.32 and 0.7 percent, respectively, exceeding only the soil occurring with the *Juniperus/Artemisia -Purshia* association.

The soil surface had some characteristics specific to this unit. Approximately 54.7 percent of its area was bare. Root crowns of perennial herbs occupied approximately 4.1 percent of the soil surface area. These values were only slightly greater than occurred on the soil surface with the *Juniperus / Artemisia -Purshia* association. Characteristically, several species of herbaceous perennials occupied a single small space on the soil surface (fig. 27). In addition, pentagonal configurations occurred on the soil, but they were more weakly developed than those characteristic of the soil found with the *Juniperus/Artemisia / Festuca -Lupinus* association. These peculiar shapes often imparted a microaspect of accelerated erosion. Frost heaving, however, appeared to be the primary cause of this feature.

Juniperus/Artemisia/Agropyron -Astragalus Association

This association occupied locations representing the most xeric conditions of the study area (fig. 28). It was characteristic of south- and southwest-facing slopes with loamy Brown soils. Although total cover of perennial herbs (9.6 percent) and shrubs (7.8 percent) were greater than in some associations, other plant factor and soil combinations indicate the relative xerism of the unit.

A primary characteristic of this unit as compared with the others was the complete absence of *Festuca idahoensis* in measured stands. The species was present but occurred only in dense, protective shade of *Juniperus occidentalis*, and was not found on the observation plots. Annual species were present, but they were generally less conspicuous than in other associations. One species, *Eriogonum baileyi*, attained its maximum constancy rating (84 percent) in this unit as compared with the others.

The vegetation in this association was characterized partly by the comparative amounts of *J. occidentalis*, *Artemisia tridentata*, and *Agropyron spicatum*. Cover of *J. occidentalis*, averaged 27.7 percent. Mature trees were not

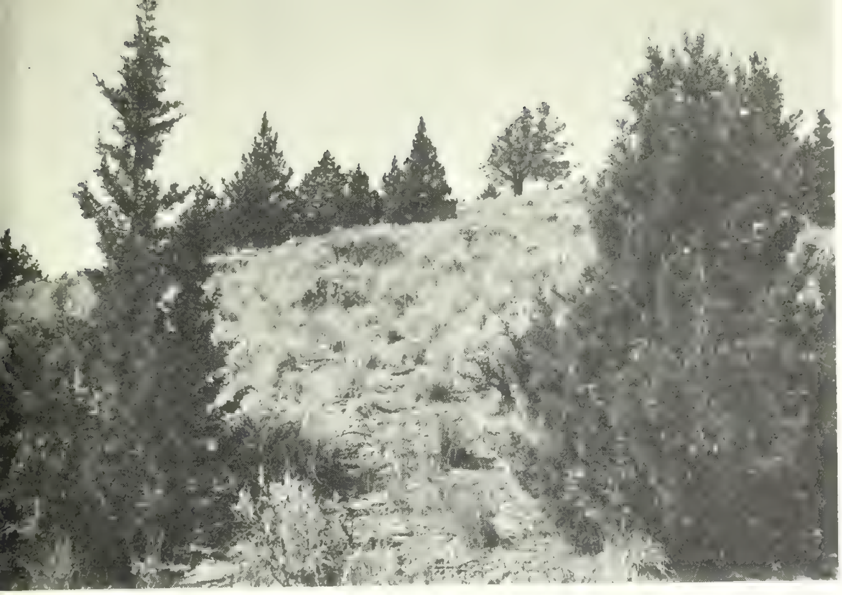


Figure 28
Stand representative of the *Juniperus/Artemisia/Agropyron-Astragalus* association. This site represents the most xeric conditions of the units described.

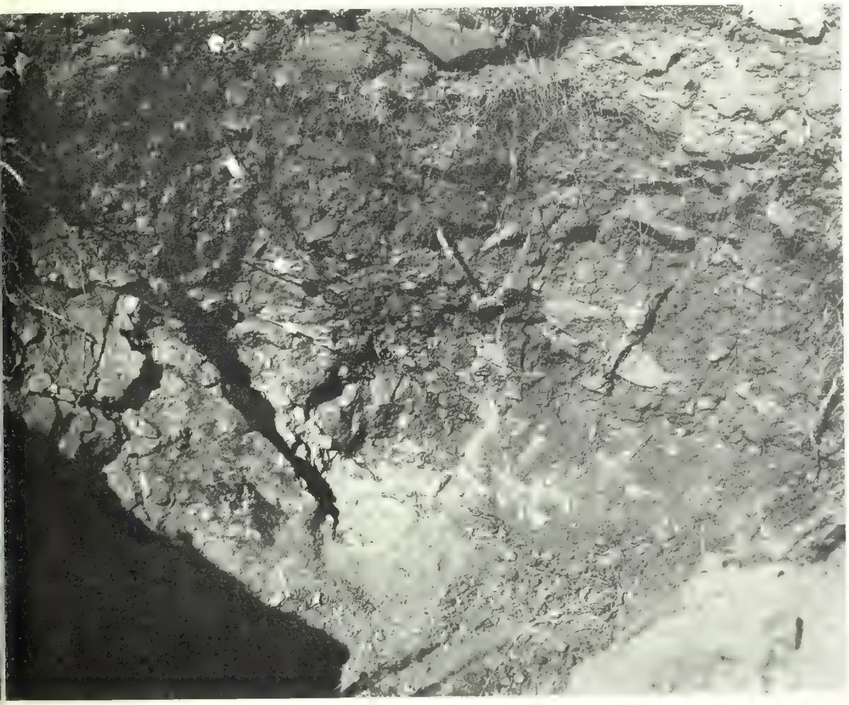


Figure 29
Soil profile of series IX occurring with the *Juniperus/Artemisia/Agropyron-Astragalus* association. Friability and stoniness of the clayey B horizon allows good root penetration. Compare with figure 18.

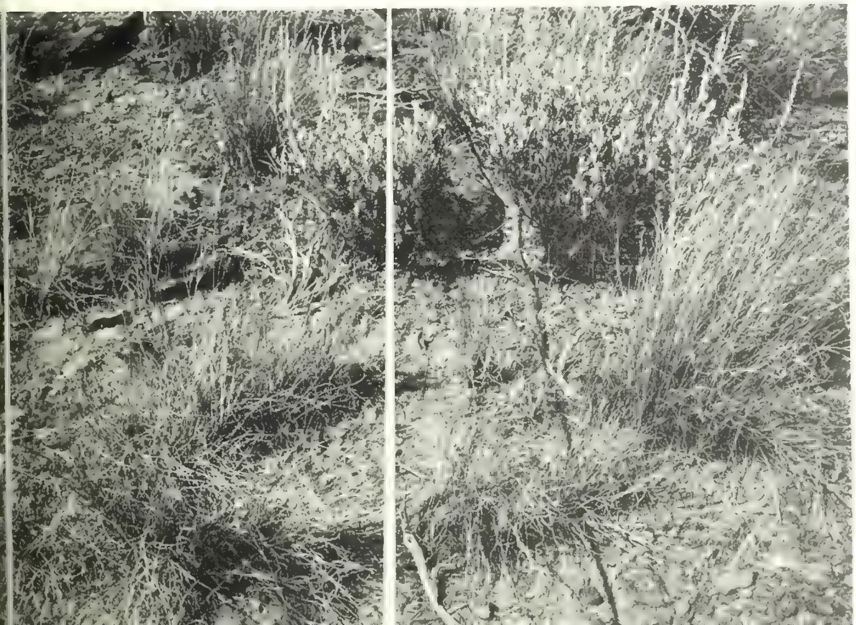


Figure 30
Detail of the soil surface and understory vegetation related to the *Juniperus/Artemisia/Agropyron-Astragalus* association. The abundance of small stones on the soil surface is characteristic of this unit.

as large or well developed as they were in other associations. *A. spicatum* had a cover of 7 percent, exceeded only in the *Juniperus/Artemisia/Agropyron* association. Cover of *A. tridentata* was 6.7 percent. Stand density of this species was 26 plants per 0.02 acre, and mature plant height averaged 1.26 feet.

Astragalus lectulus was quite specific to this association. It had a constancy rating of 100 percent with a cover value of 0.1 percent. The species occurred in two other units, the *Juniperus/Festuca* and *Juniperus/Agropyron* associations, but had constancy ratings of only 60 and 17 percent, respectively, and was not found on the observation plots.

This association was comparatively deficient in perennial herbaceous species. Only 13 different species occurred in sufficient quantities and abundance to provide some basis for characterization. Eight of these, *A. spicatum*, *Poa secunda*, *Koeleria cristata*, *Achillea millefolium*, *Phlox douglasii*, *Astragalus* sp., *Erigeron linearis*, and *Astragalus lectulus*, attained 100-percent constancy. The remaining five, *Agoseris* sp., *Eriophyllum lanatum*, *Stipa thurberiana*, *Sitanion hystrix*, and *Eriogonum umbellatum*, had constancy ratings of 50 percent or less.

The soil occurring with the *Juniperus/Artemisia/Agropyron-Astragalus* association was a Brown loam formed from rhyolitic-andesitic colluvium (series IX). Solum depth was 21 inches. Large stones occupied 50 percent of the profile volume. Below 21 inches, 90 percent of the soil volume was large stones. A discontinuous caliche often occurred at approximately 21 inches below the surface. Very few roots extended below this area.

The heaviest part of the B horizon was a clay. Structure of this clayey layer was strong and blocky with hard, dry consistence but friable when moist. This friability, in addition to solum stoniness, allowed deeper root penetration than might be expected (fig. 29). Available water storage capacity in the 2- to 14-inch soil zone was 1.21 inches, the lowest capacity of any of the zonal soils (table 3). Organic matter and total nitrogen of the A horizon were 1.63 and 0.08 percent, respectively.

The soil surface was covered with an abundance of small stones which provided an aspect of an erosion pavement (fig. 30). This was a natural phenomenon and must not be interpreted as an induced pavement created by accelerated erosion. Most of these small stones were lichen covered, and there was no evidence of soil displacement.

Discussion

Vegetation-Soil Relationships

Plant communities and the soils supporting them are functional products of the same large environmental factors (climate, organisms, relief, parent material, and time) (Major 1951; Jenny 1941). Therefore, it should be expected that direct relationships exist between interpreted categories of the two complexes. If this occurred, it would be relatively simple to characterize ecosystems by relating general vegetation and soil characteristics obtained by field surveys.

Some early workers indicated this to be true, although categorical units of soil or vegetation were not identified. Griffiths (1902) claimed that when *Agropyron spicatum* was associated with *Artemisia* spp. in the northern Great Basin, soils were almost invariably stony and fertile. Kearney *et al*. (1914) suggested the possibility of correlating vegetational distribution with soil chemical and physical properties. Graham (1937) recognized that altitudinal zonation of vegetation was due primarily to climatic factors, but the zones were often divisible on the basis of edaphic or physiographic factors.

Only in the past two decades has much work been done to correlate taxonomic vegetation and soil units. A major problem in identifying direct associations between the two complexes is related to the different disciplines under which classification of each has evolved. Most soils in the United States have been classified with an agricultural bias which has resulted in essentially a technical classification (U. S. Bur. Plant Indus., etc. 1951). With the development of a more comprehensive system, all or most of this bias should be eliminated (U. S. Soil Conservation Service 1960). Natural vegetation, on the other hand, has been classified more or less under a natural system even though plant succession has often been ignored and community separations have not been specific enough to delineate natural groupings with relatively homogeneous characteristics.

Spilsbury and Tisdale (1944) found that *Agropyron spicatum* was dominant on practically every soil type they encountered. However, they noted marked differences in density, height, and yield of the species depending on soil depth. Later, Tisdale (1947) described three vegetation zones (*Agropyron-Artemisia*, *Agropyron-Poa*, and *Agropyron-Festuca*) and found them to be correlated with three great soil groups, Brown, Chestnut, and Chernozem. Within each zone, however, he recognized edaphic and biotic communities characterized by changes in species presence and dominance.

Gardner and Retzer (1949) inferred that soil series level interpretations were adequate for classifying wildland soils in most cases. Later, Retzer (1953) pointed out more definitely that the soil series was the most useful unit for classifying wildlands on the basis of vegetation-soil correlations. Poulton[6], however, using polyclimax concepts to classify climax communities in the northeastern Oregon Columbia Basin, showed that each type of climax was associated with a particular group of soil series. Anderson (1956) showed that certain range "sites" in eastern Oregon were related to definite groups of soil series when zonal soils were involved. Eckert[7], after classifying some climax *Artemisia* types in southeastern Oregon, also found that a climax type was associated with numerous soil series. Dyrness[8] classified climax communities associated with azonal soils in the ponderosa pine zone in southern Oregon. He showed that direct vegetation-soil association occurred at the phase of soil-type level of interpretation if characteristics other than those used for profile descriptions were considered.

These investigations show conflicting opinions concerning the categorical level of soil associated directly with climax plant communities. The results indicate that in addition to differences in the way the two complexes are classified, compensatory environmental factor interactions strongly influence these relationships. This was summarized well by Poulton and Tisdale (1961) who concluded that factor compensation may result in apparently identical plant communities occurring on two or more taxonomic soil units or that different plant communities may occur on the same taxonomic soil unit.

The relationships between the interpretive categories of the vegetational and soil components of the ecosystems delimited in this study are varied. Table 6 illustrates the relation between tentatively classified taxonomic soil units and the plant associations with which they occur.

Table 6.—Relation between tentatively classified soils and plant associations in the central Oregon juniper zone

Series and phase number	Generalized type or phase of type description	Plant association
Series I	Chestnut loam from rhyolitic-andesitic colluvium on northerly slopes	*Juniperus/Artemisia/Festuca*
Series II shallow, nonstony phase	Shallow, nonstony sandy loam Regosol over gravelly loam alluvium and rhyolitic-andesitic colluvium on northern slopes	*Juniperus/Artemisia/Festuca-Lupinus*
Series III	Brown loam from friable tuffaceous material on northwesterly slopes	*Juniperus/Festuca*
Series III very stony phase	Very stony Brown loam from friable tuffaceous material on southeasterly slopes	*Juniperus/Festuca*-*Purshia* variant
Series IV	Weakly developed Brown loam from mixed rhyolitic-andesitic colluvium and aeolian sands on northerly slopes	*Juniperus/Festuca*
Series II: moderately deep, extremely stony phase	Moderately deep, extremely stony, sandy loam Regosol over cracked or closely packed basalt on northerly slopes	*Juniperus/Artemisia/Agropyron-Chaenactis*
Series V	Strongly developed Brown loam from coarse river- and lake-laid sediments containing basalt fragments on undulating uplands	*Juniperus/Artemisia/Agropyron*
Series VI	Strongly developed Brown loam from loess, very fine river sands, and small basalt fragments on undulating uplands	*Juniperus/Artemisia/Agropyron*
Series VII	Brown sandy clay loam from a thin layer of rhyolitic-andesitic colluvium over indurated tuffaceous material on northeasterly slopes	*Juniperus/Agropyron*
Series VII: shallow phase	Shallow Brown sandy clay loam from a thin layer of rhyolitic-andesitic colluvium over indurated tuffaceous material on northerly slopes	*Juniperus/Agropyron*
Series VIII	Brown loam from rhyolitic-andesitic colluvium on southeasterly slopes	*Juniperus/Agropyron*: *Purshia* variant
Series II: deep, nonstony phase	Deep, nonstony, sandy loam Regosol over a buried, loamy, stony B2 horizon on northeasterly slopes	*Juniperus/Artemisia-Purshia*
Series II: moderately deep, very stony phase	Moderately deep, very stony, sandy loam Regosol over closely packed and cemented rhyolitic-andesitic colluvium on easterly slopes	*Juniperus/Agropyron-Festuca*
Series IX	Brown loam developed from rhyolitic-andesitic colluvium on southwesterly slopes	*Juniperus/Artemisia/Agropyron-Astragalus*

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[6] Poulton, Charles E. Ecology of the non-forested vegetation in Umatilla and Morrow Counties, Oregon. 166 pp. 1955. Ph.D. thesis on file Washington State University.

[7] See footnote 2.

[8] Dyrness, Christian Theodore. Soil-vegetation relationships within the ponderosa pine type in the central Oregon pumice region. 217 pp. 1960. Ph.D. thesis on file Oregon State University.

Two primary assumptions are made upon examination of the data. With azonal soils, soils with immature profile characteristics, the phase of soil series type level of interpretation provides direct correlation with a specific plant association. In this case, four associations are found with specific phases of the same soil series—the *Juniperus/Artemisia/Festuca-Lupinus*, *Juniperus/Artemisia/Agropyron-Chaenactis*, *Juniperus/Artemisia-Purshia*, and *Juniperus/Agropyron-Festuca* associations. Zonal soils, soils having relatively mature profile characteristics, show little direct affinity for a specific plant association, regardless of level of interpretation. For example, the *Juniperus/Festuca* association occurred with two soil series and a phase of one of these series; the *Juniperus/Artemisia/Festuca* association occurred with one soil series.

Azonal soils.—The azonal soils encountered in this study are developing on parent materials of relatively recent origin. They have not reached equilibrium with the current environment and, generally, possess uniform profile characteristics. Therefore, factors genetically unrelated to the soils, including subsoil characteristics, are creating the differences in vegetation.

Phases of the soil-series-type interpretations were based on depth, stoniness, and nature of the underlying material. The deep, nonstony phase of series II, occurring with the *Juniperus/Artemisia-Purshia* association, was separated primarily on depth (45 inches) and nonstoniness. Rooting depth is not mechanically restricted, but the sandy nature of the soil allows for rapid water infiltration and drainage, deep water penetration, and comparatively excessive evaporation from near the surface. Consequently, more precipitation is needed to maintain effective, available water than in finer textured, shallower soil (Lutz *et al.* 1947). Lateral soil moisture drainage from positions above the location of this soil may supply additional water to the subsoil. As a result, this soil favors shrubby species such as *Artemisia tridentata* and *Purshia tridentata*, which characteristically root deeply in addition to maintaining roots in the surface horizons. Available soil moisture in the surface horizons is apparently not maintained long enough to allow a major expression of herbaceous species.

In contrast to the preceding soil, the shallow, nonstony phase of series II supporting the more luxuriant community of the *Juniperus/Artemisia/Festuca-Lupinus* association is shallower (16 inches), overlying a gravelly, loamy material. The internal water relations between the two soils, measured by available soil moisture storage capacity in the 2- to 14-inch soil zone, are nearly the same. However, the proximity of the underlying strata to the surface of this soil provides a better environment by increasing storage of available water at a place where it is more effective. Roots are common in the underlying material of this soil, but very few occur in the same strata of the deeper soil. In addition, the nature of the plant community modifies the environment to make it more effective. The comparatively high cover of perennial herbs reduces water evaporation from the soil surface, which probably results in increased effectiveness of total precipitation.

More subtle changes in soil characteristics as related to their associated vegetations exist between the *Juniperus/Artemisia/Agropyron-Chaenactis* and *Juniperus/Agropyron-Festuca* associations. The soils are nearly identical except for the nature of the underlying material and stoniness of the solum. The soil occurring with the *Juniperus/Artemisia/Agropyron-Chaenactis* association has 50 percent of its volume occupied by large stones, and it overlies cracked or closely packed bedrock which allows some root penetration. The soil occurring with the *Juniperus/Agropyron-Festuca* association has slightly less volume occupied by large stones (35 percent), but it overlies large stones which have been cemented with carbonate or silicate precipitates. The cementation prevents root penetration (Veihmeyer and Hendrickson 1948). Depth to the underlying material is the same in both soils. Available moisture storage in the 2- to 14-inch soil zone is only slightly different, 0.87 inch in the *Juniperus/Artemisia/Agropyron-Chaenactis* association and 0.97 inch in the *Juniperus/Agropyron-Festuca* association. Therefore, the penetrability of the underlying material to roots is probably a primary factor associated with the vegetational differences. *Juniperus occidentalis* and *Artemisia tridentata* are more strongly expressed in the *Juniperus/Artemisia/Agropyron-Chaenactis* association, where they can root deeper and not be subjected to competitive stresses as intense as caused by the cemented stratum occurring in the soil supporting the *Juniperus/Agropyron-Festuca* association.

In summary, direct vegetation-soil correlation with azonal soils can be shown at the phase of soil-type level of interpretation if phase separation considers the nature of the underlying material as well as solum characteristics. If solum characteristics only are considered, direct correlation becomes nonexistent and differences in plant associations are harder to explain.

Zonal soils.—The nonspecific vegetation-soil correlation of those associations occurring with zonal soils indicates that environmental factor interactions and compensations strongly influence the occurrence and dispersion of the plant communities. Relationships among the following factors as they affect the soil moisture regime and root growth appear to be the most important:

1. Texture, structure, and thickness of the densest part of the B horizon
2. Stones on and in the soil
3. Solum depth
4. Nature of the underlying material
5. Intensity and duration of insolation as indicated by slope aspect

This assumption is illustrated in table 3, which shows a discrepancy between available soil moisture storage capacity in the 2- to 14-inch soil zone and the relative mesic condition of the units. The soil of the most mesic unit does not have the most moisture storage capacity as indexed in this manner; the soil of the most xeric unit does not have the least capacity. However, if quantitative determinations of "effective" moisture storage could be made, a sequential arrangement would probably occur.

The comparative mesic condition of the *Juniperus/Artemisia/Festuca* association occurring with series I is improved primarily by solum stoniness and depth and the topographic position of the unit. The fact that roots are well distributed into the parent material is evidence of the soil effectiveness, even though the densest portion of the B horizon has a clay texture and strong, blocky structure.

The presence of clayskins on individual soil peds in this horizon is indicative of clay colloids leaching from surface horizons. These characteristics indicate that a claypan could have formed but the high stone content (50 percent) has prevented this from occurring. At the same time, the stones have provided for more "porous" soil conditions (Lutz and Chandler 1946), allowing good water percolation and reducing mechanical impedence to root growth. The clayey texture of all the subsoil allows for maximum water storage. The northerly aspect provides for minimum insolation (Geiger 1957) and reduced evaporation. As a result, the precipitation falling on this soil is more effective in adding to and supplying effective, available soil moisture.

The *Juniperus/Festuca* association is supported by strikingly different soils representing two series. The efficiency of the two soils is equalized by compensating effects of texture and structure of the densest part of the B horizon, solum depth, and the nature of the underlying material. The shallow, clayey textured, relatively strong structured subsoil of series III reduces the effective soil moisture and impedes root growth as compared with the deeper, loamy, less well-developed subsoil of series IV. However, the same amount of precipitation is effective longer in the subsoil of series III because of its texture and structure characteristics, and some moisture is probably drawn from the underlying friable-and-porous-when-wet tuffaceous material. These factors compensate for the shallowness of the soil to supply the same amount of effective soil moisture as series IV. These soils, when compared with series I occurring with the *Juniperus / Artemisia / Festuca* association, are more droughty because of the shallow, nonstony characteristics of series III and the coarser texture of series IV.

The increase in cover of *Purshia tridentata* and reduction in cover of *Festuca idahoensis* in the *Purshia* variant of the *Juniperus/ Festuca* associations is related to stoniness of the stony phase of series III and slope aspect. The stones (50 percent by volume) modify the clayey texture and strong structure of the subsoil (Bradfield and Jamison 1939) to provide less resistance to root penetration of *Purshia tridentata*. Also, the easterly aspect favors the development of this species. However, the increased insolation with a corresponding rise in soil surface temperature apparently approaches lethal conditions for *Festuca idahoensis*. Nevertheless, the stones on and in the soil provide slower soil heating and less heat loss (Lutz and Chandler 1946), compensating partially for the increased insolation and the northerly slope aspect of the normal position of the association. The resultant effect is the maintenance of dominance of *Festuca idahoensis* in the herbaceous layer, although in a reduced state, and no significant change in cover of species other than *Purshia tridentata*.

Series V and VI, which occurred with the *Juniperus / Artemisia / Agropyron* association, are quite similar morphologically to series I, which occurred with the *Juniperus / Artemisia / Festuca* association. However, the solums of series V and VI are rock free, and a claypan has developed near the soil surface. As a result, the biological effectiveness of these soils is reduced (Bonner and Galston 1952, Carlson 1925, Kramer 1945), even though available soil moisture storage capacity exceeds that of all other soils encountered in this study. Root growth is restricted by the claypan (Veihmeyer and Hendrickson 1948) and, consequently, the effectiveness of the available soil moisture is reduced. In addition, the nonstoniness of the soils and the level aspect reduce moisture effectiveness through water vaporization in the soil and evaporation from the soil created by longer, more intense insolation.

Although two taxonomic soil units occur with the *Juniperus / Artemisia / Agropyron* association, their apparent biological effectiveness is the same. The variation in position and thickness of the claypan and the nature of the underlying material of the two soils compensate to provide equivalent soil environments. Few roots are present in the relatively deep, thick clayey zone of series V, and no roots grow through it. In series VI, few roots also occur in the shallower, thinner, slightly coarser clayey zone. However, some roots penetrate this soil layer and grow into the looser underlying material to take advantage of the growth-supporting potential in this soil zone. As a result, the plant growth influences of the deeper, thicker, denser claypan of series V are equalized by the shallower, thinner, coarser claypan of series VI. Consequently, the combined characteristic of the plant communities on both soils represent the vegetational component of the same ecosystem.

The relative abundance of comparatively xeric species, particularly *Agropyron spicatum*, in the *Juniperus / Agropyron* association is peculiar since the easterly aspect would normally indicate comparatively good moisture conditions. However, solum and soil surface stoniness (35 and 18 percent, respectively) and the texture and nature of the underlying material of series VII occurring with this association compensate the topographic position of the unit.

The stones reduce the rate of heating as well as heat loss which favors relatively mesic conditions. However, the stones on and in this soil reduce its effective volume. Also, the soil separates of the sandy clay loam and clayey surface and subsoils are apparently of such size and distribution to allow close packing. This results in a reduction of porosity and a corresponding reduction of available moisture storage capacity. With the exception of the zonal soil occurring with the *Juniperus/Artemisia/Agropyron-Astragalus* association, moisture storage is less in this soil than in any of the other zonal soils. In addition, the indurate tuffaceous material restricting root growth adds to the droughty condition of the entity. The direct and indirect effects of these characteristics overcome the slope aspect effects and result in a xeric community in an area which might be mistakenly classified comparatively mesic.

The loam surface horizon and clay loam subsoils of series VIII, penetrability of the substratum, and the more southerly aspect account mainly for the increase of *Purshia tridentata* in the *Purshia* variant of the *Juniperus/Agropyron* association. The penetrable subtratum allows for relatively deep rooting of *P. tridentata*, a site requirement necessary for the species. Also, the more southerly aspect favors its development as a result of factor interactions similar to those in the *Purshia* variant of the *Juniperus/Festuca* association. The finer texture of this soil, as compared with the series VII occurring with the association, makes available soil moisture more effective and compensates for any increase in intensity and duration of insolation from a change in slope aspect. Consequently, the vegetational component of the ecosystem, except *P. tridentata*, is not materially changed.

The comparative xeric condition of the *Juniperus/Artemisia/Agropyron-Astragalus* association is primarily the result of the southerly aspect. This topographic position allows for maximum intensity and duration of insolation (Geiger 1957) with consequent maximum microclimatic temperatures during the growing season. However, the stone content of the solum (50 percent) and the rubbly characteristic of the soil surface modify the insolation effects by reducing the rate of heating as well as the possible maximum temperature of the effective soil. The stones also provide better conditions for water penetration and root growth into the clayey, strongly structured subsoils and reduce evaporation. As a result, the available soil moisture is more effective than it would be if stones were absent. In spite of these conditions, however, the insolation effects are strong enough to create the relative xeric condition. This is shown particularly in the paucity of perennial species and the extremely low cover when the plant layer dominants are not considered.

In summary, direct vegetation-soil correlation of ecosystem vegetational components associated with zonal soils cannot be made at a single categorical level of soil interpretation based on current soil classification procedures. Zonal soils, because of their relative maturity, invoke subtle changes in effective environmental conditions, which may or may not create significant vegetational changes. Therefore, factors not readily identified in the field or whose compensatory or interacting influences cannot be quantitatively measured must be considered when an ecosystem is characterized or differences among ecosystems are rationalized.

Texture, structure, and thickness relationships of the densest part of the B horizon, stones on and in the soil, solum depth, nature of the underlying material, and insolation provide some striking correlations and differences within and among the ecosystems and their plant communities on zonal soils in the central Oregon juniper zone.

Ecological Status of the Central Oregon Juniper Zone

Climax is a concept familiar to everyone dealing with classification of natural vegetation. Numerous definitions of climax exist (Braun-Blanquet 1932, Weaver and Clements 1938, Odum 1953, Oosting 1956), and they all connote a terminating and dynamically stable plant community determined and maintained by climate. It remains for the worker to interpolate time lapses involved, space relationships, whether the inferred climate is regional or local, physical or bio, or combinations of these, and the degree of heterogeneity characteristic of the equilibrium community.

Whittaker (1953) maintains that no completely rigorous definition of climax exists and that perhaps none need be developed. However, if vegetation is to be used for something other than aesthetic purposes, it must be classified by a system that recognizes the existing natural plant community as being climax and does not attempt to predict what it might be in the future. Selander's (1950) concept of climax and its associated community—a community representing a time phase of great stability in which successional causes cannot be observed and the future cannot be predicted—provides a workable and organized principle. Even though successional causes can be observed, such as fire indicated by charred stumps or logs, if there is no evidence of replacement or no possibility to predict future succession other than that occasioned by community dynamism, the concept remains valid. This concept of climax is the basis of the polyclimax theory which contends that many climaxes exist which are controlled by one or a few environmental factors and are not oriented to a single modal situation.

On this basis, the area in central Oregon, where *Juniperus occidentalis* is a component of relatively undisturbed vegetation, represents a natural unit of vegetation, even though some workers have doubted the existence of the pinyon-juniper zone in other parts of the Western United States as representing climax conditions. Emerson (1932) concluded, from results of studies using limited soil investigations and species lists, that the occurrence of the pinyon-juniper zone in northern New Mexico was associated with areas not occupied by "closed" stands of herbaceous vegetation and was not a true vegetational entity. He also stated that soil characteristics were incidental influences in the way they controlled growth of grasses. These conclusions were similar to those of Cottle (1931) who stated that xeric grasses dominated the vegetation of southwestern Texas and woody plants occurred only in places where rocks or other factors prevented full expression of the grasslands. Emerson (1932) did show that available soil moisture was greater in areas occupied by trees.

Both Emerson (1932) and Cottle (1931) contradicted themselves in these studies. They showed that pinyon pine and juniper, in their study areas, grew where other vegetation could not. Also, they stated that available soil moisture was greater in the pinyon-juniper areas than in associated desert grasslands. These facts strongly indicate the presence of an environment with conditions favorable for the development of a natural vegetational unit.

Woodbury (1947) concluded the pinyon-juniper zone is a natural entity after studying the distribution of "pigmy" conifers (*Juniperus osteosperma, J. monosperma, J. scopulorum, Pinus edulis*, and *P. monophylla*) in Utah and northeastern Arizona. He showed that these species were best adapted to ridges, canyons, or rough slopes with coarse, rocky, or shallow soils. He also showed that the upper and lower limits of these species were set by soil moisture excesses or deficiencies. These excesses or deficiencies, however, are not controlled by climatic factors alone; they interact with the absorptive, storage, and water-supplying powers of the soil to influence effective soil moisture.

Eckert (1957), after characterizing some *Artemisia* types in central Oregon, showed a lower unit of effective soil moisture below which *Juniperus occidentalis* did not exist although other environmental factors were similar. In this area, he concluded that the species made its maximum growth on rocky outcrops, steep slopes, or intermittent drainageways where the water-supplying power of the soil was slightly greater than the maximum requirement of climax *Artemisia tridentata* or *A. arbuscula* communities.

These conclusions of Woodbury (1947) and Eckert (1957), as well as the results of other studies (Merkle 1952, Rasmussen 1941, Woodbury 1933, Woodin and Lindsey 1954), support the hypothesis that natural plant communities characterized partly by juniper and/or pinyon pine exist and that the prevailing climate is suitable for the perpetuation of these communities. The present study strengthens this conclusion by showing that *Juniperus occidentalis* is a dominant and characteristic species of specific plant associations unaffected by influences other than those occurring naturally.

Recognizing that the central Oregon juniper zone is a natural vegetational entity and that there are specific taxonomic vegetation-soil units within the area has provided a realistic base for management. The current vegetational potentials of these units are defined in terms of kinds and amounts of specific plant species and the relationships between soils and vegetation of the units. Also, if characteristic vegetational components are missing, the ecosystems can still be identified for management purposes on the basis of soil and topographic characteristics. For example, a range manager may have a grazing unit composed mostly of the *Juniperus/Artemisia/Festuca* association where past grazing has deteriorated the desirable cattle forage. Since he knows that the vegetational potentials of the association are approximately 11- and 5-percent cover of *Festuca idahoensis* and *Agropyron spicatum*, respectively, his management will be adjusted accordingly. He will not be satisfied with only 2- and 3-percent cover of these species as demonstrated in the *Juniperus/Agropyron-Festuca* association.

Following polyclimax terminology, the *Juniperus/Artemisia/Agropyron* association is considered the climatic climax of the zone. The association occurs on undulating topography and loamy soils that are moderately drained. The validity of this assumption may be questioned because of the paucity of *Juniperus occidentalis* and the abundance of *Agropyron spicatum* and *Artemisia tridentata*. The energy relationships within and among species were not determined in this study. Consequently, the point cannot be isolated where the influence of a species within any of the associations ceases or becomes insignificant. It is certain, however, that *J. occidentalis* has an influence on the energy relationships within the *Juniperus/Artemisia/Agropyron* association. The species provides shade to modify the microclimate of the entity and removes water and nutrients from the soil that would otherwise be available to other species.

The remaining associations described in this study are considered topoedaphic climaxes. Factors related to the topography and soils of these units appear to be major controlling influences on the distribution of the vegetation. These factors and their relationships within and among the units were discussed in the preceding section.

The vegetation of the study area could have been classified with the continuum concept (Curtis and McIntosh 1951, Whittaker 1951) if single species were considered independently. A family of distribution curves, based on foliage cover, would show that each species has its own distribution center away from which it declines gradually or rapidly as it approaches the margin of its ecological amplitude. This family of curves would also show overlapping ranges among species. For example, *Festuca idahoensis* varies from 0.4-percent cover in the *Juniperus/Artemisia/Agropyron* association to approximately 11-percent cover in the *Juniperus/Artemisia/Festuca* and the *Juniperus/Festuca* associations. *Agropyron spicatum* varies from 0.9-percent cover in the *Juniperus/Artemisia-Purshia* association to approximately 9-percent cover in the *Juniperus/Artemisia /Agropyron* association. The entire range of cover values of *A. spicatum* among the associations is contained within the cover range of *F. idahoensis*. This substantiates the fact that species groupings very rarely are specific to a single environment and that very rarely does a specific environment completely exclude a species (Selleck 1960, Curtis and McIntosh 1951). Arranging the species into the resulting pattern of complex curves would illustrate the diversity of vegetation but would have little practical value from the land management point of view.

The plant communities could also have been classified with the monoclimax philosophy proposed by Clements (1916). He postulated that climax developed through a certain successional pattern to the "highest type" which is synonymous with a "formation," a unit of vegetation determined and controlled by regional climate. Areas within the formation not conforming to the climax "type" were designated "disclimax," "preclimax," or "postclimax" with reference to vegetation on disturbed sites, dry sites, or moist sites.

Under this system of classification, the *Juniperus /Artemisia/Festuca, Juniperus /Artemisia / Festuca- Lupinus, Juniperus /Festuca,* and *Juniperus/Artemisia /Agropyron-Chaenactis* associations would be considered postclimaxes and the *Juniperus / Agropyron, Juniperus / Artemisia -Purshia, Juniperus /Agropyron-Festuca*, and *Juniperus /Artemisia /Agropyron-Astragalus* associations as "preclimaxes" of the *Juniperus /Artemisia/Agropyron* association, the climatic climax of the zone. From the standpoint of grazing, this kind of classification infers either something better for grazing (postclimax) or something worse (preclimax). Confronted with such a classification, the land manager would have little basis for management since he would be dealing with intangible kinds of units. Cain (1947) aptly expressed this view when he concluded that true climax develops only on medium sites and that linking all stable communities to the climax is highly hypothetical and serves no useful purpose.

In summary, the present study confirms the concepts of Tansley (1935), Billings (1952), Daubenmire (1952), Selander (1950), and Selleck (1960) that the whole of vegetation represents a complex of ecosystems which are natural units of the landscape. Each ecosystem contains a vegetational component which can be classified as an entity easily recognized and adapted to land management.

Some Practical Applications

The best current use of nonarable lands in the central Oregon juniper zone is forage production for grazing animals. This study has demonstrated that discrete landscape units, ecosystems, exist in the area and that each has its own biological potential. Consequently, each unit also has specific management requirements. Recognition of these facts by the land manager is essential to assure optimum and sustained forage production for the grazing animals.

Classification and Inventory

A preliminary phase of any range management program involves mapping to show, among other things, the location and distribution of vegetation types. The mapping job is often done in accordance with instructions outlined by the Inter-Agency Range Survey Committee (U. S. Department of Agriculture 1937). The map units as defined by this committee are the vegetation types and are based on the current aspect of vegetation without regard to the ecological status or the recognition of specific units within these types that have specific management characteristics. Subsequent management is then based on the type as a whole. Such faulty vegetation classification places plant communities with different productive potentials and successional patterns in the same category. The resultant effect is chaotic, because a land manager does not know his goals with certainty and cannot correctly interpret the impact of management on the resource.

For example, a typical range survey would probably consider all the described ecosystems as a single unit. Subsequent cattle range management would be based on averages for all ecosystems, showing, for example, the average cover of *Festuca idahoensis* (4.5 percent) and *Agropyron spicatum* (4.2 percent) as the preferred cattle forages. With reference to the first species, stocking rates would be reduced in six out of nine cases or maintained or increased in three out of nine cases, depending on the location of the "key" management area, to fulfill the objective of sustained optimum production of forage. For *Agropyron spicatum*, stocking rates would be reduced in five or maintained or increased in four out of nine cases. In all cases, however, such management decisions are completely unrealistic because of the different productive potentials among the ecosystems.

It is recognized that defined ecosystems very often are not of sufficient areal extent in any one location to constitute a mapping unit or a management unit. The important factor is to recognize, by observation of differences in vegetational, soil, topographic, or other characteristics, that such entities exist and must be considered in classifying and managing rangelands. Emphasis by others on this point (Costello 1957, Ellison 1949, Parker 1954) has stressed the need for placing range classification on a sound natural basis.

The apparent difficulty involved in mapping, inventory, and subsequent planning is overcome simply by including each ecosystem as a part of a mapping complex and recognizing the basic characteristics of each as contributory, but independent, integers of the complex. These procedures are being used by some agencies and private operators managing native vegetation by incorporating results of similar studies (Dyrness[9], Eckert[10], Poulton[11]). The question "How can management of an area be effective if that area consists of numerous, independent units?" can rightfully be asked. The individual manager or user must decide if current or predicted economics warrant individual management of each ecosystem or if some units will be sacrificed by basing management on others.

Range Condition and Trend

Another type of practical application concerns evaluation of range condition and trend based on guides or standards developed for each vegetation-soil unit. Range condition is range health, the relative successional position of a site with regard to the inherent potential of the site. Range trend is the direction of change in condition and shows whether a range site is holding its own or becoming more or less productive as compared with the site potential.

Range condition classification should strongly consider the kind of animal that is or will be using a particular area. For example, all the associations described are ecologically in excellent condition. However, when the grazing animal is considered, condition classifications among associations will vary. The vegetation of the *Juniperus/Artemisia/Festuca* association would be considered excellent for cattle because of the abundance of desirable cattle forages. On the other hand, this same unit would rank low for deer because of the relative paucity of deer forage, normally shrubs and forbs. With reference to the *Juniperus/Artemisia Purshia* association, the rating of this area would be relatively high for deer but low for cattle because of the comparative abundance of deer forages and absence of cattle forages.

Compared with other units, the *Purshia* variant of the *Juniperus/Agropyron* association would rank high in condition for deer but slightly lower for cattle. Stable soil is assumed in all these hypothetical condition ratings. It would behoove a range manager, then, to rate range condition to the animal as well as to the area rather than the latter alone. This would implement range classification and use by defining the most practicable grazing use of specific associations.

Range trend must also consider the kind of animal using an area. For example, continued heavy cattle use in the *Juniperus/Artemisia-Purshia* association would reduce and perhaps eventually eliminate the grasses and some forbs. The resultant vacuum in the plant community would probably be filled by an increase in density and cover of shrubs, particularly *Purshia tridentata*, a highly desirable deer forage. Thus, at a given time, an upward trend could be indicated for deer range and a downward trend for cow range.

The validity of condition and trend classification is determined largely by the way the vegetation is classified initially. If, for example, the whole area was classified as a single entity, condition and trend determinations would be based partly on the average foliage cover of *Festuca idahoensis* (4.5 percent). A sampling location to determine range condition might be located in the *Juniperus /Artemisia /Agropyron* association where, under existing ecological conditions, foliage cover of this species is only 0.4 percent and individual plants occur only in the deep shade of shrubs and trees. Subsequent condition ratings would always be extremely low, based on the assumption that the sampled area should have at least 4.5-percent foliage cover of *F. idahoensis*. As a result, the grazing load would be reduced in an attempt to allow for an increase of the species, something that would be unlikely to happen within reasonable time. In this case, forage would be wasted that could otherwise be utilized if the initial vegetation classification provided for separation of specific associations.

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[9] See footnote 8.

[10] See footnote 2.

[11] See footnote 6.

Range Rehabilitation

Future range rehabilitation programs for either game or livestock can be enhanced by the results of this study. If a decision were made to improve game forage conditions by seeding *Purshia tridentata*, those associations located on aspects receiving moderate insolation and having soils which allow deep root penetration with little mechanical impedence would be selected initially to give the best results. With reference to cattle range improvement, drought-tolerant, shallow-rooting species would be selected for sites having soils similar to those found with the *Juniperus /Artemisia / Agropyron* association. The claypan close to the surface of these soils would inhibit growth of deep-rooting species unless it is mechanically altered by cultural practices such as deep plowing. On the other hand, deeper rooting species which can take advantage of deeper soil moisture storage would be used in sites with soils similar to those found with *Juniperus /Artemisia / Festuca* association. The clayey but stony subsoils and northerly aspect of this unit provide more biologically effective moisture than is found in the soils occurring with the *Juniperus / Artemisia /Agropyron* association.

Summary

1. The pinyon-juniper zone in Oregon, characterized in the tree overstory by *Juniperus occidentalis* and referred to as the juniper zone, is subdivided into three physiographic units. These are based on soil parent materials and include: (1) aeolian sands in central Oregon, primarily Deschutes, Crook, and Jefferson Counties; (2) residual igneous material located in north-central, south-central, and southeastern Oregon; and (3) old sediments located in the upper regions of the John Day and Crooked Rivers.

2. In the central Oregon juniper zone, the plant association and soils of nine relatively undisturbed ecosystems and variants of two are defined and characterized in accordance with polyclimax concepts. Simultaneous analysis and interpretation of selected vegetational, soil, and topographic characteristics provided classificatory criteria for each unit. Vegetational characteristics included foliage cover, basal area, heights and density of shrubby and suffrutescent species, and constancy. Soil characteristics used were (1) complete morphological soil descriptions including estimates of bare soil surface, amounts of stone on and in the soil, available soil moisture storage capacity in the 2- tc 14-inch soil zone, organic matter, and total nitrogen in the A horizon and (2) textural analyses of the A and the AC horizons in azonal soils and the A and B horizons in zonal soils. The only topographic characteristic useful for characterization purposes was slope aspect. Elevation, slope position, and slope steepness appeared to have little influence on species or community distribution.

3. A taxonomic key to the associations was developed from vegetational, soil, and topographic characteristics easily recognized in the field. Areas where vegetation was disturbed by grazing or other causes were easily classified as to specific associations with this key.
4. The associations described are in climax condition. Successional causes could not be determined and future changes could not be predicted.
5. Direct correlations existed between interpreted phases of azonal soil types and four of the associations. This occurred when soil unit interpretation included the nature of the underlying material and the effects of this material on plant growth.
6. Direct correlations did not always exist between interpreted categories of zonal soils and specific associations. Three of the five associations with zonal soils occurred with more than one interpretive soil unit. A single soil series was directly associated with the other two plant associations.
7. With those associations occurring with zonal soils, cause-and-effect relationships between vegetation and soils were refined by consideration of interactions and compensations among the following factors: (1) texture, structure, and thickness of the densest part of the B horizon; (2) stones on and in the soil; (3) solum depth; (4) nature of the underlying material; and (5) intensity and duration of insolation as indicated by slope aspect.
8. Practical applications of the findings to range and wildlife habitat management and additional research are suggested.

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Appendix 1.

Scientific Names, Authors, and Common Names of Species Mentioned in the Text[12]

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[12] Nomenclature and authorities for grasses from Hitchcock (1950), for trees from Little (1953), and for shrubs and forbs from Abrams (1940-60). Kelsey and Dayton (1942) is the primary source for common names.

SCIENTIFIC NAME AND AUTHORITY	COMMON NAME
Achillea millefolium L.	common yarrow
Agoseris Raf.	agoseris
Agropyron spicatum (Pursh) Scribn. & Smith	bearded bluebunch wheatgrass
Artemisia L.	sagebrush
Artemisia arbuscula Nutt.	low sagebrush
Artemisia tridentata Nutt.	big sagebrush
Astragalus (Tourn.) L.	milkvetch
Astragalus lectulus S. Wats.	purple woolly-pod
Bromus tectorum L.	cheatgrass brome
Carex filifolia Nutt.	threadleaf sedge
Chaenactis douglasii (Hook.) Hook. & Arn.	Douglas chaenactis
Chrysothamnus nauseosus (Pall.) Britt.	rubber rabbitbrush
Chrysothamnus viscidiflorus (Hook.) Nutt.	Douglas rabbitbrush
Collinsia parviflora Dougl.	littleflower collinsia
Collomia grandiflora Dougl.	collomia
Cryptantha ambigua (A. Gray) Greene	cryptantha
Erigeron filifolius Nutt.	threadleaf fleabane
Erigeron linearis (Hook.) Piper	lineleaf fleabane
Eriogonum Michx.	eriogonum
Eriogonum baileyi S. Wats.	Bailey's eriogonum
Eriogonum microthecum Nutt.	slenderbrush eriogonum
Eriogonum ochrocephalum S. Wats.	woolly eriogonum
Eriogonum sphaerocephalum Dougl.	rock eriogonum
Eriogonum umbellatum Torr.	sulfur eriogonum
Eriophyllum lanatum (Pursh) Forbes	woolly eriophyllum
Festuca idahoensis Elmer	Idaho fescue
Festuca octoflora Walt.	sixweeks fescue
Gayophytum lasiospermum Greene	groundsmoke
Grayia spinosa (Hook.) Moq.	spiny hopsage
Grossularia velutina (Greene) Cov. & Britt.	desert gooseberry

Juniperus monosperma (Engelm.) Sarg.	one-seed juniper
Juniperus occidentalis Hook.	western juniper
Juniperus osteosperma (Torr.) Little	Utah juniper
Juniperus scopulorum Sarg.	Rocky Mountain juniper
Koeleria cristata (L.) Pers.	prairie junegrass
Leptodactylon pungens (Tor.) Rydb.	granite gilia
Linanthus harknessii (Curran) Greene	Harkness gilia
Lomatium triternatum (Pursh) Coult. & Rose	Nineleaf lomatium
Lupinus L.	lupine
Mentzelia albicaulis Dougl.	whitestem mentzelia
Montia perfoliata (Donn) Howell	miner's lettuce
Penstemon cinereus Piper	ashen penstemon
Phlox douglasii Hook.	Douglas phlox
Pinus L.	pine
Pinus edulis Engelm.	pinyon pine
Pinus monophylla Torr. & Frem.	singleleaf pinyon
Pinus ponderosa Laws.	ponderosa pine
Poa secunda Presl.	Sandberg bluegrass
Purshia tridentata (Pursh) DC.	antelope bitterbrush
Ribes cereum Dougl.	wax currant
Sitanion hystrix (Nutt.) J. G. Smith	bottlebrush squirreltail
Stipa comata Trin. & Rupr.	needle-and-thread
Stipa thurberiana Piper	Thurber needlegrass
Tetradymia canescens DC.	gray horsebrush

Appendix 2.

Tentative Descriptions of Soil Series and Phases with Related Associations

SERIES I: Chestnut loam from rhyolitic-andesitic colluvium on northerly slopes.
Related association: *Juniperus/Artemisia/Festuca*

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-3	Very dark-brown (10YR 2/2 moist), dark-gray (10YR 4/1 dry) loam; moderate, coarse platy breaking to single grain; loose, very friable, very slightly sticky, very slightly plastic; pH 6.0; common roots; boundary abrupt, smooth.
A12	3-10	Very dark-brown (10YR 2/2 moist), dark-brown (10YR 3/3 dry) silt loam; weak, medium, subangular blocky; soft, friable, slightly sticky, slightly plastic; pH 6.5; abundant roots; boundary clear, smooth.
B1	10-15	Dark-brown (10YR 3/3 moist), dark yellowish-brown (10YR 3/4 dry) silty clay loam; weak, fine, angular blocky; hard, firm, slightly sticky, slightly plastic; pH 7.0; common to abundant roots; boundary clear, wavy.
B21	15-20	Dark yellowish-brown (10YR 3/4 moist), dark-brown (10YR 4/3 dry) clay loam; moderate, medium, angular blocky; hard, firm, sticky, plastic; pH 7.0; few to common roots; boundary clear, wavy.
B22	20-30	Dark yellowish-brown (10YR 4/4 moist), dark yellowish-brown (10YR 4/4 dry) clay; strong, medium, angular blocky; very hard, firm, sticky, plastic; pH 8.0; few to common roots; boundary abrupt, smooth; common clayskins on the ped surfaces.
C(Dr)	30+	Dark yellowish-brown (10YR 4/4 moist), yellowish-brown (10YR 5/4 dry) clay loam; weak, fine, angular blocky; firm, hard, slightly sticky, slightly plastic; pH 8.0; few roots. Soil mainly thin coatings around large rhyolitic and andesitic stones.

Large rhyolitic or andesitic stones compose 45 to 50 percent of the solum volume. Calcareous deposits are common on ped surfaces and stones in the lower B and C horizons. Pumice is distributed throughout the profile. The surface horizon is strongly vesicular.

SERIES II: Sandy loam Regosol on north and east slopes in the Brown zone and developed from pumiceous sands.
Related associations: *Juniperus/Artemisia/Festuca-Lupinus*
Juniperus/Artemisia/Agropyron-Chaenactis
Juniperus/Artemisia-Purshia
Juniperus/Agropyron-Festuca

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-3	Dark-brown (10YR 3/3 moist), gray-brown (10YR 5/2 dry) sandy loam; medium, thick platy breaking to single grain; loose, nonsticky, nonplastic; pH 6.0; common roots; boundary abrupt, smooth.
A12	3-7	Dark-brown (10YR 3/3 moist), brown (10YR 5/3 dry) sandy loam; single grain; loose, nonsticky, nonplastic; pH 6.5; abundant roots; boundary clear, smooth.

AC	7-14	Dark yellowish-brown (10YR 3/4 moist), brown (10YR 5/3 dry) sandy loam; single grain; soft, loose, nonsticky, nonplastic; pH 7.0; abundant roots; boundary clear, smooth.
C	14-22	Dark yellowish-brown (10YR 3/4 moist), brown (10YR 4/3 dry) sandy loam; single grain; loose, nonsticky, nonplastic; pH 7.5; common to abundant roots; boundary clear, wavy.

The soil contains approximately 30 percent pumice by volume. The surface horizon is strongly vesicular. The soil overlies unrelated material.

Four phases of this series type are recognized. Phase separation was based on depth to the underlying material, characteristics of the underlying material, and solum stoniness. Each phase occurs with a separate association.

Shallow, nonstony phase: Shallow (16 inches), nonstony over gravelly, loamy, alluvium and rhyolitic and andesitic stones; 50 percent of the underlying material is large stones; roots are common in the underlying material; occurs on north to northeast slopes.

Related association: *Juniperus/Artemisia/-Festuca-Lupinus*

Moderately deep, extremely stony phase: Moderately deep (26 inches), extremely stony over cracked or closely packed basalt; the solum contains approximately 50 percent large stones; 90 percent of the underlying material is large stones; few roots penetrate the cracks of the underlying material; occurs on northwest to northeast slopes.

Related association: *Juniperus/Artemisia/Agropyron-Chaenactis*

Deep, nonstony phase: Deep (45 inches), nonstony over a loamy, B2 horizon; 50 percent of the underlying material is small stones; very few roots extend into the underlying material; occurs on north to northeast slopes.

Related association: *Juniperus/Artemisia-Purshia*

Moderately deep, very stony phase: Moderately deep (23 inches), very stony over large, closely packed rhyolitic and andesitic stones cemented with carbonates and/or silicates; the solum contains approximately 35 percent large stones; roots do not penetrate the cemented material; occurs on east slopes.

Related association: *Juniperus/Agropyron-Festuca*

SERIES III: Brown loam from tuffaceous material on northwesterly slopes.

Related association: *Juniperus/Festuca*

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-2	Very dark-gray-brown (10YR 3/2 moist), gray-brown (10YR 5/2 dry) loam; moderate, medium, platy; soft, loose, slightly sticky, slightly plastic; pH 6.0; abundant roots; boundary abrupt, smooth.
A12	2-6	Very dark-gray-brown (10YR 3/2 moist), dark-gray-brown (10YR 4/2 dry) loam, moderate, medium, crumb; soft, very friable, slightly sticky, slightly plastic; pH 6.5; abundant roots; boundary abrupt and smooth.
B1	6-9	Dark yellowish-brown (10YR 4/4 moist), dark-brown (10YR 4/3 dry) clay loam; moderate, fine, angular blocky; hard, friable, slightly sticky, slightly plastic; pH 6.5; common roots; boundary clear, smooth.

B2	9-13	Dark-brown and dark yellowish-brown (10YR 3/4, 4/4 moist), dark-brown (10YR 4/3 dry) clay; moderate, medium prismatic breaking to strong, medium, angular blocky; very hard, very firm, sticky, plastic; pH 7.0; roots common; boundary clear, wavy.
B3	13-18	Brown (10YR 4/3 moist), yellowish-brown (10YR 5/4 dry) clay loam; moderate, medium, angular, blocky; hard, friable, slightly sticky, slightly plastic; pH 7.5; few to common roots; boundary clear, wavy.
C(Dr)	18+	Tuffaceous material very hard when dry becoming friable when moist. Roots are common, apparently penetrating when the material is wet.

The modal type of this series is relatively stone free; 5 percent of profile volume is occupied by stones. Pumice is distributed throughout the profile. This soil is normally on north- to northwest-facing slopes. The surface horizon is strongly vesicular.

Very stony phase: Very stony Brown loam from friable, tuffaceous material; the solum contains approximately 50 percent large rhyolitic and andesitic stones unrelated to the solum; occurs on southeasterly slopes; horizon number, sequence, and characteristics are the same as the series type.

Related association: *Juniperus/Festuca-Purshia* variant

SERIES IV: Weakly developed Brown loam from mixed rhyolitic andesitic colluvium and aeolian sands on northerly slopes.

Related association: *Juniperus/Festuca*

HORIZON	DEPTH (inches)	DESCRIPTION
A1	0-9	Very dark-gray-brown (10YR 3/2 moist), dark-gray-brown (10YR 4/2 dry) loam; moderate, medium, granular; soft, loose, slightly sticky, slightly plastic; pH 6.0; abundant roots, boundary clear, smooth.
B1	9-15	Dark-brown (10YR 3/3 moist), dark-brown (10YR 4/3 dry) loam; weak medium, subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; pH 6.0; common roots; boundary clear, wavy.
B2	15-28	Dark-brown (10YR 3/3 moist), yellowish-brown (10YR 5/6 dry) silt loam; weak, medium, subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; pH 6.0; common roots; boundary clear, wavy.
C	28+	Dark-brown (10YR 4/3 moist), yellowish-brown (10YR 5/4 dry) gravelly loam; massive; soft, loose, slightly sticky, slightly plastic; pH 6.5; few roots; mixed rhyolitic-andesitic colluvium and aeolian sands.

This soil is relatively stone free to 24-inch depth. Below this point, stones occupy 40 percent of the profile volume. Pumice is distributed throughout the profile.

SERIES V: Strongly developed Brown loam from river- and lake-laid sediments and occurring on undulating uplands.

Related association: *Juniperus/Artemisia/Agropyron*

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-2	Very dark-gray-brown (10YR 3/2 moist), light-gray-brown (10YR 6/2 dry) loam; weak, medium, platy breaking to single grain; loose, very friable, nonsticky, nonplastic; pH 6.5; roots few; boundary abrupt, smooth.
A12	2-6	Dark-brown (10YR 3/3 moist), gray-brown (10YR .5/2 dry) silt loam; weak, fine, subangular blocky; soft, friable, slightly sticky, slightly plastic; pH 7.0; abundant roots; boundary abrupt, smooth.
A3	6-9	Dark-brown (10YR 3/3 moist), brown (10YR 5/3 dry) silty clay loam; moderate, medium, subangular blocky; slightly hard, friable, slightly sticky, slightly plastic; pH 7.0; common roots; boundary abrupt, wavy.
B21	9-15	Dark-brown (10YR 3/3 moist), dark-gray-brown (10YR 4/2 dry) silty clay; moderate, medium prismatic breaking to moderate, medium, angular blocky; hard, very firm, sticky, plastic; pH 7.5; roots few; boundary abrupt, wavy.
B22	15-23	Dark-brown (10YR 4/3 moist), dark yellowish-brown (10YR 3/4 dry) clay; strong, medium prismatic breaking to strong, medium angular blocky; very hard, very firm, sticky, plastic; pH 8.0; few roots; boundary abrupt, wavy; few clayskins.
B3	23-26	Yellowish-brown (10YR 5/4 moist), yellowish-brown (10YR 5/4 dry), silty clay loam; weak, medium, angular blocky; slightly hard, firm, slightly sticky, plastic; pH 8.0; few roots; boundary abrupt, smooth.
C(Dr)	26^{+}	River- and/or lake-laid sediments with partially decomposed basalt stones. No roots.

A strongly developed soil relatively stone free, 5 percent by volume. The B horizon definitely restricts root penetration. Calcareous deposits on soil peds in the B horizon and on the few stones in the B and C horizons. A discontinuous caliche at approximately 28 inches. Pumice distributed throughout the profile. Occasional small pockets of nearly pure pumice in the B horizon. The surface horizon is strongly vesicular.

SERIES VI: Strongly developed Brown loam from loess, very fine sands and small basalt fragments and occurring on undulating uplands.

Related association: *Juniperus/Artemisia/Agropyron*

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-2	Dark-brown (7.5YR 3/2 moist), gray-brown (10YR 5/2 dry) loam; moderate, medium, platy; soft, friable, slightly sticky, nonplastic; pH 7.0; few roots; boundary abrupt, smooth.
A12	2-8	Very dark-gray-brown (10YR 3/2 moist), brown (10YR 5/3 dry) silt loam; weak, medium, subangular blocky; slightly

		hard, friable, slightly sticky, slightly plastic; pH 7.5; abundant roots; boundary abrupt and wavy.
B22	8-10	Dark-brown (10YR 3/3 moist), brown (10YR 5/3 dry) clay loam; moderate, medium prismatic breaking to weak, medium, angular blocky; very hard, friable, sticky, plastic; pH 7.5; common roots; boundary clear, wavy.
B3	10-13	Dark-gray-brown (10YR 4/2 moist), pale-brown (10YR 6/3 dry) silty clay loam; weak, medium, angular blocky; hard, firm, slightly sticky, slightly plastic; pH 8.0; few roots, boundary gradual, wavy.
C(Dr)	13+	Loess, very fine river sands, and partially decomposed basalt fragments; pH 8.0; few roots to 24 inches, none below this.

A relatively stone-free soil (5 percent by volume). Root penetration restricted but not stopped by the B horizon. Pumice scattered throughout the profile. The surface horizon is strongly vesicular. Calcareous deposits in the lower B and in the C horizons.

SERIES VII: Brown sandy clay loam from rhyolitic-andesitic colluvium over indurate tuffaceous material on northeasterly slopes.

Related association: *Juniperus/Agropyron*

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-3	Very dark-gray-brown (10YR 3/2 moist), gray-brown (10YR 5/2 dry) sandy clay loam; moderate, medium, platy; soft, very friable, very slightly sticky, very slightly plastic; pH 6.0; few roots; boundary abrupt, smooth.
A12	3-9	Very dark-gray-brown (10YR 3/2 moist), dark-gray-brown (10YR 4/2 dry) loam; weak, fine, subangular blocky; soft, friable, very slightly sticky, very slightly plastic; pH 6.5; common and abundant roots; boundary abrupt, wavy.
B1	9-18	Dark-brown (10YR 3/3 moist), dark-brown (10YR 4/3 dry) silty clay loam; moderate, medium, angular blocky; slightly hard, friable, slightly sticky, slightly plastic; pH 7.0; common and abundant roots; boundary clear, smooth.
B21	18-32	Dark-brown (10YR 4/3 moist), dark-yellowish-brown (10YR 4/4 dry) silty clay loam; strong, medium, angular blocky; hard, friable, slightly sticky, slightly plastic; pH 7.5; roots common; boundary abrupt, smooth.
B22	32-40	Dark-brown (10YR 4/3 moist), dark-yellowish-brown (10YR 4/4 dry) clay loam; moderate medium prismatic breaking to strong, medium, angular blocky; very hard, friable, sticky, plastic; pH 8.0; few roots; boundary clear, wavy; few clayskins.
C(Dr)	40-44	Mixed rhyolitic-andesitic colluvium. Thin clayey material coating the stones. Roots extend into the rock cracks.
D	44+	Indurate tuffaceous material nonfriable when moist.

The solum contains approximately 35 percent large stones. Few peds and rocks in the lower

B horizon coated with a calcareous deposit. Pumice distributed through the profile. The surface horizon is strongly vesicular and has many small pebbles adhering to the bottom of the plates.

Shallow phase: Shallow (20 inches) occurring near the tops of northerly slopes and having a weakly expressed B1 horizon; horizon number, sequence, and characteristics except thickness are the same as the series type.

Related association: *Juniperus/Agropyron*

SERIES VIII: Brown loam from rhyolitic-andesitic colluvium on southeasterly slopes.

Related association: *Juniperus / Agropyron-Purshia* variant

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-3	Very dark-gray-brown (10YR 3/2 moist), gray-brown (10YR 5/2 dry) loam; moderate, coarse, platy; soft, very friable, very slightly sticky, very slightly plastic; pH 6.0; few roots; boundary clear, smooth.
A12	3-7	Dark-brown (10YR 3/3 moist), brown (10YR 5/3 dry) loam; weak, fine, subangular blocky; soft, very friable, slightly sticky, slightly plastic; pH 6.5; roots abundant; boundary clear, smooth.
A3	7-12	Dark-brown (10YR 3/3 moist), dark-brown (10YR 4/3 dry) silt loam; moderate, fine, subangular blocky; slightly hard, very friable, slightly sticky, slightly plastic; pH 7.0; roots abundant; boundary abrupt, wavy.
B1	12-15	Dark-brown (10YR 3/3 moist), dark-brown (10YR 4/3 dry) silty clay loam; moderate, fine, angular blocky; slightly hard, very friable, slightly sticky, slightly plastic; pH 7.5; roots common; boundary abrupt, wavy.
B22	15-20	Dark-gray-brown (10YR 4/2 moist), dark-yellowish-brown (10YR 4/4 dry) clay; strong, medium to fine, angular blocky; very hard, firm, sticky, plastic; pH 8.0; few roots; boundary abrupt, wavy.
C(Dr)	20+	Mixed rhyolitic-andesitic colluvium with thin, sandy clay material coating the stones; pH 8.0; roots penetrate the cracks between the stones.

The solum contains approximately 40 percent large stones. Few calcareous deposits on soil peds and stones in the lower B horizon. Siliceous deposits on rocks in the C and lower B horizons. Pumice distributed throughout the profile. The surface horizon is strongly vesicular and has many small pebbles adhering to the bottom of the plates.

SERIES IX: Brown loam from rhyolitic-andesitic colluvium on south to southwesterly slopes.

Related association: *Juniperus/Artemisia/Agropyron-Astragalus*

HORIZON	DEPTH (inches)	DESCRIPTION
A11	0-4	Very dark-gray-brown (10YR 3/2 moist), gray-brown (10YR 5/2 dry) loam; weak, medium platy; soft, very friable, slightly sticky, slightly plastic; pH 6.0; common roots; boundary abrupt, smooth.
A12	4-7	Dark-brown (10YR 3/3 moist), dark-gray-brown (10YR 4/2 dry) silt loam; weak, medium, subangular blocky; soft, friable, slightly sticky, slightly plastic; pH 6.5; common to abundant roots; boundary clear, wavy.
B21	7-16	Dark-yellowish-brown (10YR 3/4 moist), dark-brown (10YR 4/3 dry) silty clay loam; moderate, medium, angular blocky; very hard, friable, sticky, plastic; pH 7.5; common roots, boundary clear, wavy.
B22	16-21	Dark-brown (10YR 3/3 moist), dark-brown (10YR 4/3 dry) clay; strong, medium, angular blocky; very hard, friable, sticky, very plastic; pH 8.0; few roots; boundary clear, irregular; common clayskins.
C(Dr)	21+	Large, closely packed rhyolitic-andesitic colluvium with clay loam or silty clay on the stone surfaces.

Stones occupy approximately 50 percent of the profile volume to the C(Dr) horizon. Stones occupy approximately 90 percent of this horizon. Some stones and soil peds in the C(Dr) and lower B horizons have calcareous deposits on their surfaces. Siliceous deposits are common on stones in the C(Dr) horizon. A discontinuous caliche often occurs at approximately 25 inches below the surface. The surface horizon is strongly vesicular. Pumice distributed throughout the profile.

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LUMBER YIELD and LOG VALUES of

WHITE FIR

by Eldon M. Estep and Douglas L. Hunt

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPT OF AGRICULTURE - FOREST SERVICE

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SUMMARY

Lumber grade recovery from 284 southern Oregon white fir logs was determined in a cooperative study conducted in 1961. Value of the lumber from each log was used to compute values of individual log grade-log diameter classes. Methods used to collect lumber grade yield data allowed development of basic log value information applicable to grading and scaling practices used both east and west of the Cascade Range.

Effect on lumber yield of (1) log diameter and (2) log grade is illustrated in curves which relate lumber value and log value to log size and quality. Overrun and defect observed in the study logs are graphically shown. While the log mix included in the study does not necessarily represent any sawmill's normal supply, timber processors--as well as timber buyers and sellers--can use the information reported here as a basis for predicting lumber and log values from any given mix of log grades and sizes.

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INTRODUCTION

Utilization of timber species locally referred to as "white firs" has expanded in recent years in nearly every area where these true firs grow. As a result, sawmill operators and loggers have frequently found themselves regarding white firs with increased interest. Knowledge of recovery values of white fir timber has not kept pace, however, with the transformation of the former weed trees into commercial timber. The fact that several species are generally termed "white fir" has also contributed to a lack of understanding of the actual value of white fir timbers. To provide a better basis for evaluating this timber, a cooperative study of lumber grades recovered from white fir (*Abies concolor* (Gord. & Glend.) Lindl.) was made at Medford, Oreg., in 1961. Results of that study are reported here.

The reader should keep in mind that these results are from one 3-shift study at a single mill and may not reflect average experience of white fir producers over an extended period. In fact, personnel at the cooperating sawmill report that their average defect and overrun are about half of those found in this intensive study. They suggest that this may be due to differences in volumes obtained in everyday scaling as compared with the carefully scaled volumes of the study logs.

Nonetheless, these study results are a valid indication of white fir lumber output under specific conditions. Additional studies will be valuable in building a broader sample from which white fir timber may be better evaluated. In the meantime, mill operators may relate their own experience to these study results by using simplified batch tests.

METHOD

Log Sample

At the time the log sample was chosen, white fir logs were supplied to Kogap Manufacturing Co.'s sawmill in Medford, Oreg., from two sale areas located on public lands in Jackson County, Oreg. Several true fir species were hauled to the mill together, but only *Abies concolor* logs were included in the study.

Log Selection

As logs were delivered to the storage area, white fir logs were set aside for the sample. Although most study logs were assembled as they were randomly delivered to the mill, additional logs were chosen from the mill's storage decks to provide sizes and grades not then being hauled.

The objective of providing a fair number of logs in each grade and diameter class governed sample log selection. The sample drawn, therefore, does not necessarily represent the log mix available to any given mill. To estimate the lumber yield of a given mill (using data developed in the study), relative proportions of each log grade and diameter class available to that mill must be used as weighting factors.

Log Diagraming, Grading, and Scaling

The visible surface and end characteristics of each log were critically examined in the mill yard. These characteristics were recorded on prepared forms. Thus, the relationship of the external characteristics of a log to its lumber grade yield could be studied in detail to develop tree grades or refine log grades.

Study logs were graded and scaled according to practices used on both the west side and east side of the Cascade Range. West-side official Bureau log grades[1/] for hemlock were assigned in the yard by a U.S. Forest Service regional check scaler. Before the logs were bucked, the check scaler also scaled them in the yard in accordance with Bureau scaling practices (maximum scaling length, 40 feet). This long-log sample included 284 logs.

After logs over 22 feet long were marked for bucking into two pieces, they were graded by the same Forest Service check scaler by Trial Log Grades for Associated Species (see Appendix) used on the east side of the Cascades. East-side log scale[2/] (maximum scaling length, 16 feet) was not determined until the logs had been bucked on the sawmill deck. Thus, adequate time for careful grading in the yard was allowed, as well as for observation of all log ends before the logs were scaled. A total of 520 short logs (10 to 22 feet in length) resulted when sample logs were bucked on the mill deck.

In timber appraisal on the west side of the Cascade Range, limited use is made of official Bureau rules as applied to short logs. To provide lumber grade recovery information on this basis, west-side Bureau log grades and

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[1/] Official Log Scaling and Grading Rules for the Puget Sound, Grays Harbor, Southern Oregon, Northern California, and Tillamook County Log Scaling and Grading Bureaus. 38 pp. 1954.

[2/] U.S. Forest Service. National Forest Scaling Handbook. 101 pp. 1956 revision.

scale were applied to the 520 short logs. Thus, log scale information was developed by three different scaling practices:

Scaling practice	Gross log scale (in board feet)	Defect deduction (in board feet)	Net log scale (in board feet)
West-side Bureau scale, applied to long logs	146,910	27,360	119,550
West-side Bureau scale, applied to short logs	162,610	32,100	130,510
East-side scale, applied to short logs	173,790	31,320	142,460

Logs delivered to the mill yard ranged from 12 to 40 feet in length. These were scaled as one log under west-side Bureau rules. Logs fed into the sawmill ranged in length from 10 to 22 feet. Both west-side Bureau grading and scaling rules were applied to these short logs. Official Bureau scaling differs from east-side scaling in three ways: diameter measurement, defect deductions, and maximum scaling length. These different practices result in scale variation. The variation attributable primarily to length is apparent in comparing the two west-side Bureau scales. The difference in scale attributed primarily to diameter differences can be seen by comparing west-side Bureau short-log scale with east-side short-log scale. Scale variations, due to both diameter and length, can be seen by comparing west-side Bureau long-log scale with east-side short-log scale.

Lumber Manufacture

The cooperating sawmill was equipped with a band headsaw and vertical band resaw, a combination that is representative of most mills sawing white fir. Sawing, drying, and surfacing practices of the mill were representative of industry practice.

Sawing.--Study logs were sawn per agreement to obtain the highest value from each log. Most of the white fir volume was cut into 2-inch Dimension. Selects were sawn into 4/4-, 5/4-, and 7/4-inch thickness and Shop lumber was cut to 5/4-inch thickness. A minimum volume of 1-inch Common boards was desired.

The identity of lumber sawn from individual short logs was maintained by a color code until the consecutive sawing number of the log could be written on the face of the board. On the green sorting chain, each piece of lumber was tallied by its log number, grade, and rough green dimensions.

Kiln-drying.--After the logs were sawn, study lumber was stacked for kiln-drying. Stickering and stacking were done by hand with well-designed and well-built racks. Production schedules were used to dry the lumber in end-loaded, double-track, and single-track kilns. Excessive drying degrade was not found.

Surfacing.--After kiln-drying, study lumber was dry-sorted by planing item and by the original green chain grademark. Thus, when one lot of lumber (such as 2X6 Standard) was surfaced, graded, and tallied, the surfaced dry grade yield could be compared directly with the green grade input. Grading behind the planer was accomplished by certified company graders under the supervision of the same West Coast Lumber Inspection Bureau (WCLIB) inspector who had graded the stock on the green chain.

Dimension lumber and Common boards were graded in accordance with WCLIB[3] rules. Shop and Selects were graded under Western Pine Association[4] (WPA) rules.

The surfaced dry lumber output provided the basis for all grade yield data reported herein. To determine surfaced dry yield from individual logs, green-to-dry conversion factors were needed, since lumber identity by log number was not maintained beyond the green chain. Conversion factors were obtained by determining the percentage of lumber volumes by dry grades which developed from a single green grade. By means of these green-to-dry conversion factors, the rough green grade yield of each individual log was then converted to a surfaced dry grade yield.

Analysis of Data

Data were subjected to three separate analyses: (1) by short logs, according to east-side log grading and scaling practices; (2) by long logs, according to west-side log grading and scaling practices; and (3) by short logs, under west-side log grading and scaling practices. The following procedures were used:

1. Within each log grade (east-side grade or west-side grade), the logs in each 1-inch diameter interval were combined to form a log group. The yield of surfaced dry lumber (by lumber grade) from a log group

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[3] West Coast Lumber Inspection Bureau. Standard grading and dressing rules for Douglas fir, west coast hemlock, Sitka spruce, western red cedar lumber. No. 15, 338 pp., illus. Portland, Oreg., March 1956, plus supplements.

[4] Western Pine Association. Standard grading rules for Idaho white pine, white fir, ponderosa pine, larch, sugar pine, Douglas fir, lodgepole pine, red cedar, incense cedar, Englemann spruce lumber. 166 pp., illus. Portland, Oreg. 1960.

provided the basic data for computing log values. This information also provided the basis for the lumber grade recovery tables included in the appendix.

2. The volume of surfaced dry lumber in each lumber grade was multiplied by the appropriate 1960 price (listed in the appendix), and lumber grade yield values were added to compute the total value (in dollars) of the lumber yield from each log group.

3. For each log group, the value of lumber was divided by the volume of surfaced dry lumber to give dollars per thousand board feet, lumber tally. This value ratio, referred to as unit lumber value, is a convenient index of lumber grade yield and is useful in comparing the quality of lumber produced from various grades and/or sizes of logs.

4. For each log group, the value of lumber was divided by the net log scale to give dollars per thousand board feet, net log scale. This log value ratio, referred to as unit log value, is especially meaningful to those engaged in buying and selling timber since it reflects not only the quality but also the quantity of lumber recovered.

RESULTS AND DISCUSSION--EAST-SIDE PRACTICE

The distribution of 520 study logs, graded and scaled by east-side diameter classes and log grades, is shown in table 1. Grades and sizes of logs included in the study may be considered a valid indication of log quality and sizes available from white fir timber stands in southern Oregon. Timber quality is low, and logs fit almost entirely into log grades 3 and 4. Only a few grade 2, and almost no grade 1, logs may be found.

Results of analyses of study data are presented largely in tabular and graphic form. The log volume, lumber volume, and lumber value for the logs within each log grade are shown in table 2. This summary of findings provides the basis for most of the subsequent discussion. In addition, table 2 permits further analysis of results if desired.

Lumber Grade Yield by Log Grade-Diameter Class

Grouping study logs into 6-inch diameter intervals allows one to more readily visualize the influence of log quality and log size on lumber yield. Relevant data for each of the diameter intervals have been summarized in table 3, except that diameter intervals containing less than 10 logs were omitted from this table.

The quality variability found in timber is carried over into lumber yield. Although examination of the lumber grade yield portion of table 3 shows that grouping at 6-inch intervals smooths variability, an accurate generalization of lumber grade yield is still provided.

Table 1.--Distribution of 520 white fir short logs, by diameter and log grade; southern Oregon, 1961

Diameter (inches)	Log grade[1]				
	No. 1	No. 2	No. 3	No. 4	Total
	Number				
6- 8	--	--	--	22	22
9-11	--	--	--	52	52
12-14	--	--	41	20	61
15-17	--	--	60	15	75
18-20	--	2	70	6	78
21-23	--	5	56	5	66
24-26	--	2	53	3	58
27-29	--	1	54	1	56
30-32	--	1	29	1	31
33-35	1	3	11	--	15
36-38	1	1	4	--	6
Total	2	15	378	125	520

[1] Trial Log Grades for Associated Species.

NOTE: The heavy lines enclose those log grade—diameter intervals that are included in table 3. Data from all logs except No. 1 grade are summarized in tables 10-12 of the appendix.

Table 2.--Net log scale, total lumber volume, and total lumber value for white fir, by diameter and log grade; southern Oregon, 1961

Log diameter (inches)	Log grade[1/]											
	No. 1			No. 2			No. 3			No. 4		
	Net log scale	Lumber tally	Value	Net log scale	Lumber tally	Value	Net log scale	Lumber tally	Value	Net log scale	Lumber tally	Value
	--- Bd. ft. ---		Dollars	--- Bd. ft. ---		Dollars	--- Bd. ft. ---		Dollars	--- Bd. ft. ---		Dollars
6	--	--	--	--	--	--	--	--	--	20	35	2.09
7	--	--	--	--	--	--	--	--	--	200	357	20.31
8	--	--	--	--	--	--	--	--	--	400	698	38.16
9	--	--	--	--	--	--	--	--	--	650	925	54.51
10	--	--	--	--	--	--	--	--	--	1,110	1,589	86.71
11	--	--	--	--	--	--	--	--	--	1,110	1,569	88.60
6-11	--	--	--	--	--	--	--	--	--	3,490	5,173	290.38
12	--	--	--	--	--	--	550	757	40.84	860	1,186	62.70
13	--	--	--	--	--	--	1,690	2,230	121.60	420	622	29.99
14	--	--	--	--	--	--	1,840	2,502	134.29	730	1,018	54.63
15	--	--	--	--	--	--	2,960	3,667	191.82	1,060	1,526	78.05
16	--	--	--	--	--	--	2,750	3,389	182.01	530	704	36.11
17	--	--	--	--	--	--	3,790	5,062	274.20	650	666	34.15
12-17	--	--	--	--	--	--	13,580	17,607	944.76	4,250	5,722	295.63
18	--	--	--	160	225	15.06	5,390	6,949	377.96	360	416	22.65
19	--	--	--	--	--	--	4,490	5,588	300.07	450	566	27.30
20	--	--	--	330	364	32.09	6,550	7,830	422.45	430	611	27.01
21	--	--	--	240	336	29.68	3,240	4,104	234.92	370	514	22.45
22	--	--	--	--	--	--	7,010	8,865	478.86	920	1,223	56.24
23	--	--	--	1,190	1,452	98.34	7,510	9,074	496.34	--	--	--
18-23	--	--	--	1,920	2,377	175.17	34,190	42,410	2,310.60	2,530	3,330	155.65
24	--	--	--	--	--	--	5,780	6,888	368.84	250	447	22.59
25	--	--	--	--	--	---	8,030	9,564	516.29	780	887	42.95
26	--	--	--	840	731	45.10	7,670	9,074	501.72	--	--	--
27	--	--	--	--	--	--	7,630	8,941	489.72	--	--	--
28	--	--	--	440	463	34.33	10,520	13,344	798.10	670	715	37.87
29	--	--	--	--	--	--	7,880	10,001	592.57	--	--	--
24-29	--	--	--	1,280	1,194	79.43	47,510	57,812	3,267.24	1,700	2,049	103.41
30	--	--	--	410	692	60.56	7,030	9,394	530.01	--	--	--
31	--	--	--	--	--	--	3,490	4,014	224.60	630	723	38.56
32	--	--	--	--	--	--	6,810	8,408	499.08	--	--	--
33	490	871	91.31	580	929	63.52	2,970	3,602	213.79	--	--	--
34	--	--	--	500	791	67.56	3,820	4,521	256.70	--	--	--
35	--	--	--	680	1,009	68.47	670	702	51.49	--	--	--
30-35	490	871	91.31	2,170	3,421	260.11	24,790	30,641	1,775.67	630	723	38.56
36	400	673	64.89	840	839	41.46	570	779	77.72	--	--	--
37	--	--	--	--	--	--	2,120	2,929	170.78	--	--	--

[1/] Trial Log Grades for Associated Species.

Table 3.--Log input, lumber yield, and lumber value for white fir of southern Oregon, based on east-side log grading and scaling practices, 1961[1]

LOG INPUT AND LUMBER YIELD

Item	Log grade and diameter interval						
	No. 3				No. 4		
	12-17	18-23	24-29	30-35	6-11	12-17	18-23
Logs....................number..	101	126	107	40	74	35	11
Gross log scale.....board feet..	14,670	39,840	60,470	31,330	3,690	4,540	3,210
Net log scale.......board feet..	13,580	34,190	47,510	24,790	3,490	4,250	2,530
Defect................percent..	7	14	21	21	5	6	21
Lumber tally........board feet..	17,607	42,410	57,812	30,641	5,173	5,722	3,330
Overrun...............percent..	30	24	22	24	48	35	32

GRADE YIELD (in percent of dry lumber tally)

Item	12-17	18-23	24-29	30-35	6-11	12-17	18-23
Select:							
C	1	1	2	2	2	1	0
D	0	1	2	2	0	0	0
Total	1	2	4	4	2	1	0
Shop:							
Molding	0	1	2	4	1	0	0
All Shop and Outs	1	1	4	6	0	0	3
Total	1	2	6	10	1	0	3
Common:							
Standard and Better	49	46	41	37	54	45	31
Utility	30	30	28	28	27	31	34
Economy	19	20	21	21	16	23	32
Total	98	96	90	86	97	99	97

LUMBER VALUE (in dollars)

Item	12-17	18-23	24-29	30-35	6-11	12-17	18-23
Basis:							
Per M b.m. lumber tally	53.66	54.48	56.51	57.95	56.13	51.67	46.74
Per M b.m. net log scale	69.57	67.58	68.77	71.63	83.20	69.56	61.52

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[1] Trial Log Grades for Associated Species; maximum log scaling length of 16 feet.

A significant proportion of Shop and Select lumber was produced only from the larger diameter grade 3 logs (fig. 1). In contrast to the 14 percent of Shop and Selects found in 30- to 35-inch, grade 3, white fir logs, a recent study[5] showed 43 percent of Shop and 6 percent of Selects sawed from Shasta red fir logs of the same log grade-diameter class.

As might be expected from the size and quality of white fir logs found, lumber produced was largely limited to the Common grades. This was mostly 2-inch stock. One-inch Common boards made up only 4 percent of the total lumber sawed.

Lumber Value as an Index of Lumber Grade Yield

A convenient weighted index to lumber grade yield is provided when lumber value is expressed in dollars per thousand board feet, lumber tally. Lumber quality obtained from logs of various qualities and sizes may thus be easily compared. The overall effect of log grade and diameter is presented graphically in figure 2. A unit lumber value (dollars per thousand board feet, lumber tally) was calculated from the raw study data and plotted for each log grade-diameter class. A regression line which best fitted the data was drawn for each log grade to illustrate the relationship between two variables, unit lumber value and log diameter. Generally, lumber value increased as diameter increased in log grade 3, but value fell off as log size increased in grade 4. Examination of lumber grade yields in table 3 and figure 1 shows why these relationships exist. For grade 3 logs, the total percentage of Utility and Economy lumber remained virtually unchanged, but increasing amounts of Shop and Selects were cut as log diameter increased. Only minor amounts of Shop and Select stock were cut from grade 4 logs regardless of size. Instead, percentages of Standard and Better were high in the smaller diameter range but were reduced as diameters increased. Correspondingly, Utility and Economy stock increased with increasing log size to a high of 66 percent for grade 4 logs in the 18- to 23-inch diameter class.

Log Value by Log Grade and Log Diameter

Product yield may be considered strictly in terms of lumber value. Log value, expressed in dollars per thousand board feet, net log scale, is often more useful in comparing value of lumber obtained from logs of varying grade and diameter, since logs are generally purchased on a net log scale basis. Log values for white fir logs sawed in this study are shown in figure 3.

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[5] Grantham, John B., and Hunt, Douglas L. Lumber yield and log values of Shasta red fir. Pac. NW. Forest & Range Expt. Sta. U.S. Forest Serv. Res. Paper PNW-2, 30 pp., illus. 1963.

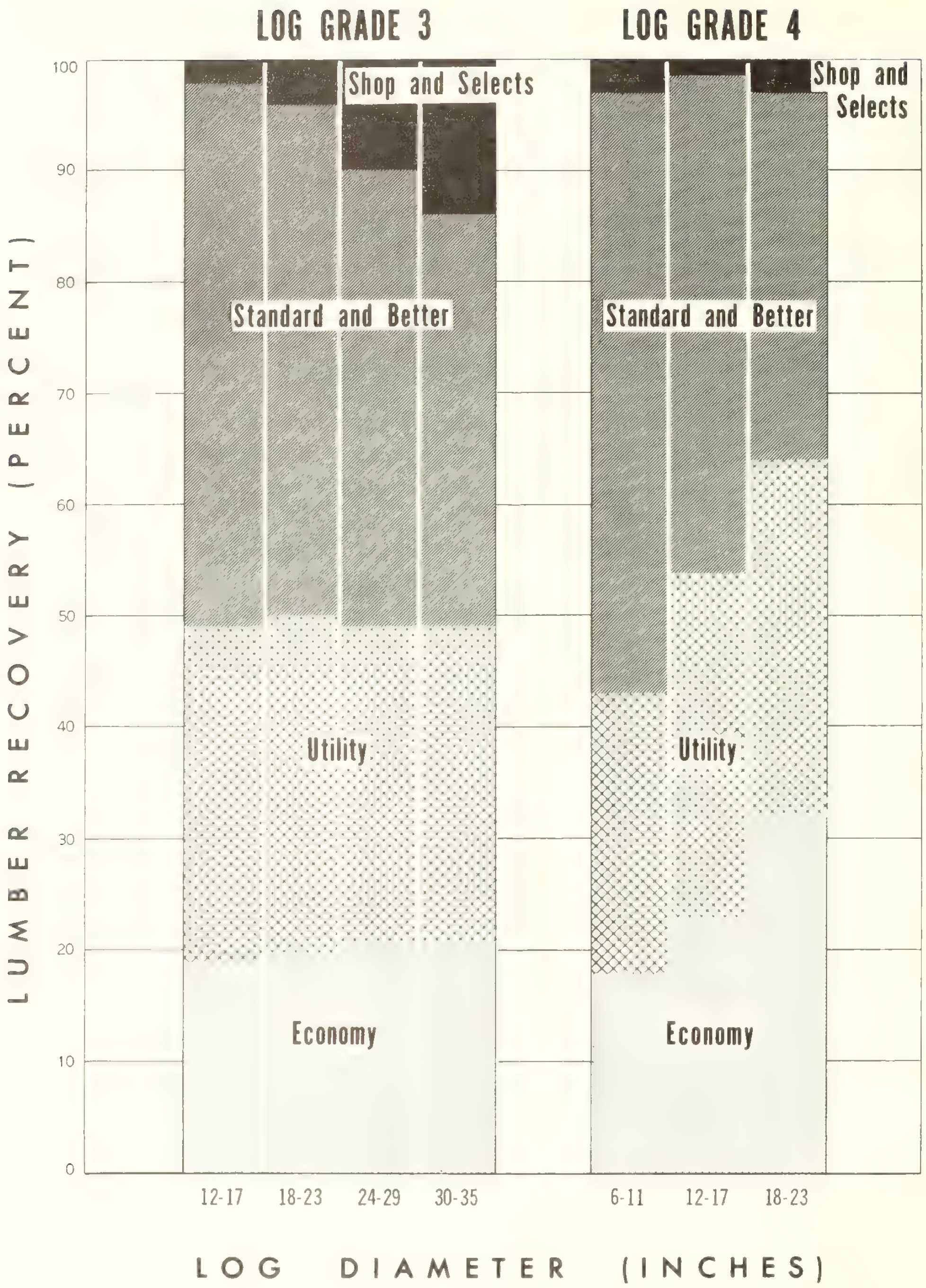


Figure 1.--Surfaced dry lumber grade recovery, by 6-inch diameter classes and by log grades, based on Trial Log Grades for Associated Species.

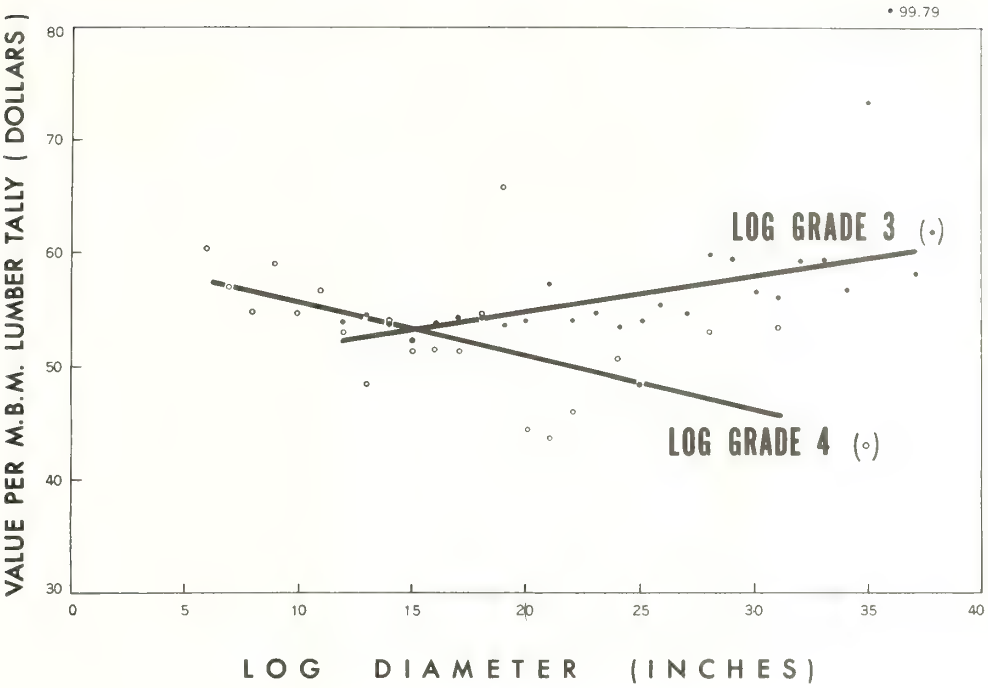


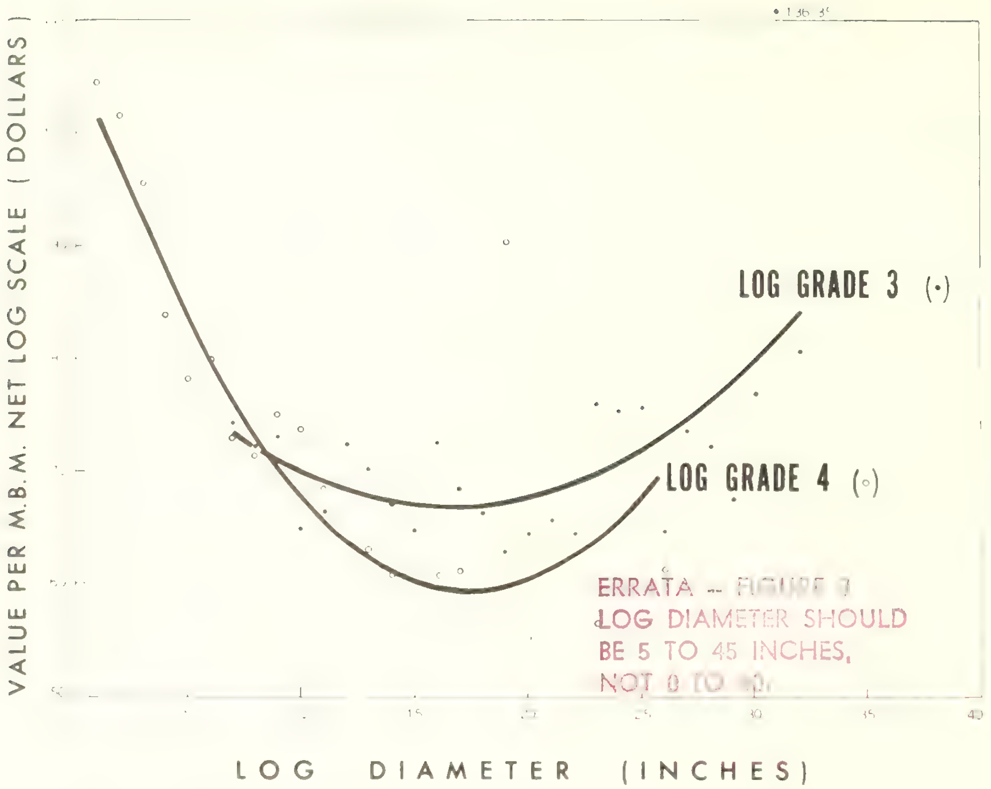
Figure 2.--Relationship of lumber value (dollars per thousand board feet, dry lumber tally basis) to log diameter by log grade (Trial Log Grades for Associated Species).

The effect of overrun (spread between lumber volume output and net log scale input) may be seen when the lumber value curves in figure 2 are compared with log values presented in figure 3. The relationship of product yield to diameter, which is linear on a lumber value basis, becomes curvilinear on a log value basis and involves unit value of lumber plus lumber volume.

Overrun

Curves of overrun for the log grades and sizes sampled are shown in figure 4. Although overrun data plotted for the diameter classes in log grade 4 generally seem intermixed with points plotted for grade 3, a covariance analysis indicates that the regression lines are significantly different. Examination of the figure shows that individual plotting points for the log grade 3 data are relatively well grouped along the grade 3 regression line. In contrast, considerably more variation is shown by the log grade 4 data. Although the plotting points seem almost randomly distributed, the calculated regression line for log grade 4 indicates that the overrun data for log grade 4 has a definite trend.

Variations in overrun such as those shown will not be new to readers accustomed to working with overruns from individual logs or small groups of logs. The multitude of combinations of log characteristics found in a single log grade-diameter class allow a wide variation in volumes recovered.



ERRATA -- FIGURE 3
LOG DIAMETER SHOULD
BE 5 TO 45 INCHES,
NOT 0 TO 40.

Figure 3.--Relationship of log value (dollars per thousand board feet, net log scale) to log diameter by log grade (Trial Log Grades for Associated Species).

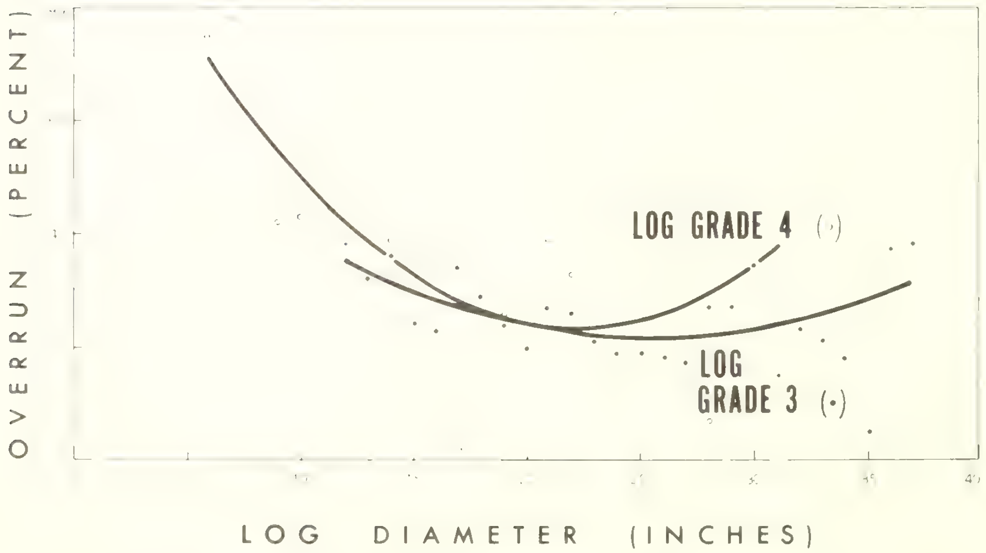


Figure 4.--Relationship of overrun to log diameter by log grade (Trial Log Grades for Associated Species).

Though all lumber in the study which would fit into a lumber grade was tallied and included in this analysis, normal operating practice at the study mill was to convert low-grade Economy material to chips. Accordingly, a higher Economy grade mix was offered to the mill's customers. Prices received were thus slightly higher than average Economy prices experienced in the region, but lumber overrun obtained by the cooperating mill was reduced.

Defect

Calculated regression lines for the percent of scaled defect are shown for the grades 3 and 4 logs sampled (fig. 5). As was the case with overrun, variation of individual diameter-class plotting points from the regression line is greater for log grade 4 than for the other log grade. Covariance analysis shows that the regression line for grade 3 is significantly different from that of log grade 4.

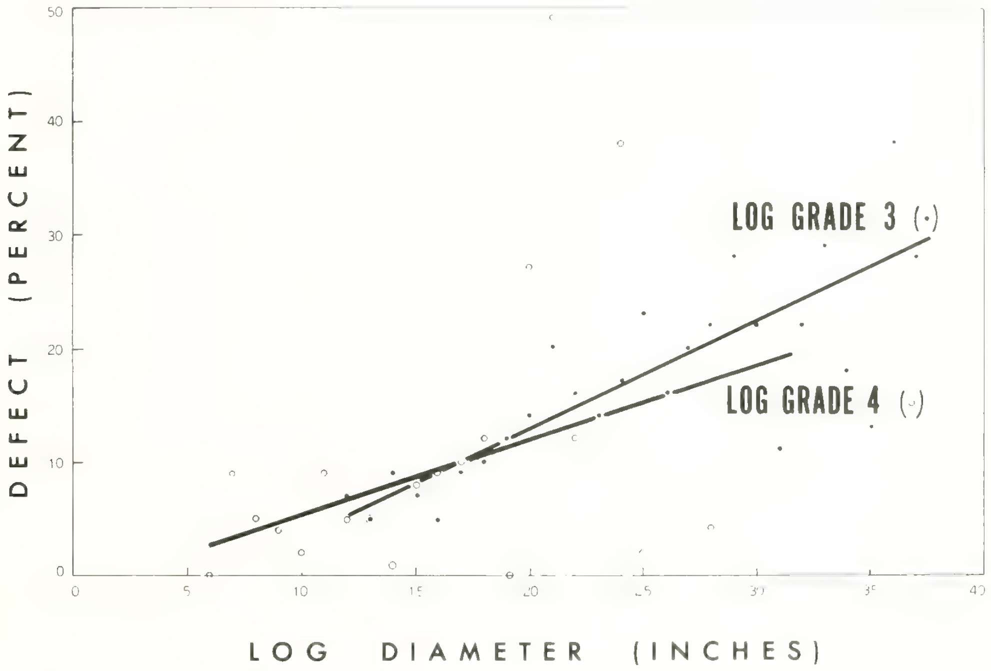


Figure 5.--Relationship of scaled defect to log diameter by log grade (Trial Log Grades for Associated Species).

RESULTS AND DISCUSSION--WEST-SIDE PRACTICE

Since the customary west-side practice is to apply Bureau grading and scaling practices to long logs, the study results obtained by applying west-side grades and scale to 520 short logs (up to 22 feet in length) are given limited treatment in this report. This section is primarily devoted to study results obtained from 284 long logs graded and scaled in accordance with west-side practice. Their distribution by quality and size classes is shown in table 4.

Table 4.--Distribution of 284 white fir long logs, by diameter and log grade; southern Oregon, 1961[1]

Diameter (inches)	No. 2	No. 3	Total
	Number		
6- 8	--	26	26
9-11	--	32	32
12-14	9	36	45
15-17	27	17	44
18-20	25	11	36
21-23	22	11	33
24-26	15	9	24
27-29	21	5	26
30-32	11	1	12
33-35	6		6
Total	136	148	284

[1] Official Log Scaling and Grading Rules for the Puget Sound, Grays Harbor, Southern Oregon, Northern California, and Tillamook County Log Scaling and Grading Bureaus.

NOTE: The heavy lines enclose those log-grade diameter intervals that are included in table 6. Data from all logs are summarized in tables 13-14 of the appendix.

Timber quality was such that sample logs fitted only west-side log grades 2 and 3. White fir logs which meet west-side specifications for Peeler and No. 1 log grades may be considered rare in the southern Oregon area sampled in this study. Log volume, lumber volume, and lumber value of the study logs are given in table 5. The 284 logs are grouped by 1-inch diameter intervals within each log grade.

Table 5.--Net log scale, total lumber volume, and total lumber value for white fir, by diameter and log grade; southern Oregon, 1961

Log diameter (inches)	Log grade[1]					
	No. 2			No. 3		
	Net log scale	Lumber tally	Value	Net log scale	Lumber tally	Value
	Bd. ft.	Bd. ft.	Dollars	Bd. ft.	Bd. ft.	Dollars
6	--	--	--	--	--	--
7	--	--	--	350	774	43.50
8	--	--	--	820	1,790	100.17
9	--	--	--	1,020	2,096	119.45
10	--	--	--	620	1,352	67.52
11	--	--	--	1,140	1,992	110.94
6-11	--	--	--	3,950	8,004	441.58
12	--	--	--	1,390	2,560	134.86
13	--	--	--	2,920	5,325	287.42
14	1,780	3,022	161.04	1,520	3,085	167.17
15	1,990	3,179	167.78	1,230	2,114	106.91
16	2,820	4,215	229.63	1,140	2,117	110.01
17	2,410	3,860	205.35	1,900	3,153	176.15
12-17	9,000	14,276	763.80	10,100	18,354	982.52
18	2,020	3,333	188.70	1,260	2,276	111.32
19	2,330	3,461	191.73	840	1,501	80.43
20	5,830	8,403	474.56	2,030	3,546	188.50
21	3,500	4,890	284.75	1,570	2,191	113.88
22	7,880	11,290	630.10	1,810	2,856	140.50
23	1,930	2,568	147.08	1,890	3,175	160.76
18-23	23,490	33,945	1,916.92	9,400	15,545	795.39
24	2,780	3,795	217.48	3,140	4,628	224.57
25	3,930	6,150	349.03	1,420	2,229	138.22
26	4,980	6,772	391.52	1,620	2,354	122.08
27	11,230	15,880	947.93	1,060	1,503	82.97
28	3,600	5,436	345.56	1,160	1,438	76.43
29	3,370	4,309	278.78	3,220	4,426	223.31
24-29	29,890	42,342	2,530.30	11,620	16,578	867.58
30	5,270	7,009	377.28	--	--	--
31	6,330	8,077	547.11	--	--	--
32	1,230	1,666	135.21	1,420	1,791	84.83
33	2,760	3,971	211.00	--	--	--
34	5,090	6,992	489.25	--	--	--
30-35	20,680	27,715	1,759.85	1,420	1,791	84.83

---

[1] Official Log Scaling and Grading Rules for the Puget Sound, Grays Harbor, Southern Oregon, Northern California, and Tillamook County Log Scaling and Grading Bureaus.

Lumber Grade Yield by Log Grade-Diameter Class

Log input and lumber output have been further summarized by 6-inch diameter intervals. These groupings facilitate comparisons of the influence of log quality and log size on product yield. Pertinent data for each of the 6-inch diameter intervals containing 10 or more logs may be found in table 6.

Table 6.--Log input, lumber yield, and lumber value for white fir of southern Oregon, based on west-side log grading and scaling practices, 1961[1]

LOG INPUT AND LUMBER YIELD

Item	Log grade and diameter interval							
	No. 2				No. 3			
	12-17	18-23	24-29	30-35	6-11	12-17	18-23	24-29
Logs......................number..	36	47	36	17	58	53	22	14
Gross log scale.......board feet..	10,300	27,970	39,370	25,750	4,340	10,850	11,740	15,030
Net log scale.........board feet..	9,000	23,490	29,890	20,680	3,950	10,100	9,400	11,620
Defect..................percent..	13	16	24	20	9	7	20	23
Lumber tally..........board feet..	14,276	33,945	42,342	27,715	8,004	18,354	15,545	16,578
Overrun.................percent..	59	45	42	34	103	82	65	43

GRADE YIELD (in percent of dry lumber tally)

Item	No. 2 12-17	No. 2 18-23	No. 2 24-29	No. 2 30-35	No. 3 6-11	No. 3 12-17	No. 3 18-23	No. 3 24-29
Select:								
C	1	2	3	4	1	1	1	1
D	0	1	2	4	0	0	0	1
Total	1	3	5	8	1	1	1	2
Shop:								
Molding	0	2	4	7	0	1	0	1
All Shop and Outs	0	2	5	6	0	2	2	3
Total	0	4	9	13	0	3	2	4
Common:								
Standard and Better	48	46	41	35	52	45	40	39
Utility	30	28	26	25	29	30	32	32
Economy	21	19	19	19	18	21	25	23
Total	99	93	86	79	99	96	97	94

LUMBER VALUE (in dollars)

Item	No. 2 12-17	No. 2 18-23	No. 2 24-29	No. 2 30-35	No. 3 6-11	No. 3 12-17	No. 3 18-23	No. 3 24-29
Basis:								
Per M b.m. lumber tally	53.50	56.47	59.76	63.50	55.17	53.53	51.17	52.33
Per M b.m. net log scale	84.87	81.61	84.65	85.10	111.79	97.28	84.62	74.66

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[1] Bureau log grades for hemlock; maximum scaling length, 40 feet.

Grouping in this manner obviously smooths variation resulting from the natural variability found in timber, but generalizations may be made from data shown in table 6 and figure 6. Figures in the grade yield portion of the table indicate that Shop and Select lumber accounted for a very small proportion of the lumber sawed from grade 3 logs. Production of Shop and Selects from grade 2 logs increased as log size increased to a total of 21 percent from 30- to 35-inch logs.

Lumber grade performance from this true fir may be contrasted with grade yields obtained in the recent study (footnote 5) of another, Shasta red fir, from the same general southern Oregon area. Grade 2 Shasta red fir logs 30 to 35 inches in diameter yielded 51 percent of Shop and Select lumber.

Lumber Value as an Index of Lumber Grade Yield

Expressing lumber value in dollars per thousand board feet, lumber tally, provides an index weighted according to lumber grade yield. This allows easy comparison of lumber quality obtained from logs of various qualities and sizes. Effect of log grade and diameter on product yield from 284 logs graded and scaled according to west-side practices may be seen in figure 7. A unit lumber value for each log grade–diameter class, calculated as described earlier, was plotted, and lines of best fit were drawn to illustrate the relationship of unit lumber value to log diameter within each log grade.

Lumber value for grade 2 logs increases with increasing diameter, but value of lumber produced from grade 3 logs decreases as log size increases. Examination of the points plotted for individual diameters shows that lumber value differences are slight between log grades below the 20-inch diameter. This suggests that the 14-inch diameter limit for grade 2 logs is an artificial limitation that might better be set at 20 inches. This would eliminate log-grading efforts to separate lumber value classes which apparently do not exist in white fir logs less than 20 inches in diameter under this grading system.

Log Value by Log Grade and Log Diameter

Logs are usually bought and sold on a net log scale basis, and a measure of product yield on this basis is especially useful. Lumber recovery values determined in this study, expressed in dollars per thousand board feet, net log scale, are shown in figure 8.

It is desirable at this point to explain why values plotted over log diameter may give horizontal lines for one log grade and an increasing or decreasing straight or curved line for another log grade. A statistical test of significance was applied to the calculated lines showing relationship of value to diameter. Only those curve forms (straight or curved lines) that could be statistically defended on the basis of significance (95-percent confidence level or greater) were shown in this report. When the data did not warrant a curve or straight line of either increasing or decreasing value, the average value for the log grade was drawn over all the diameters found in the study.

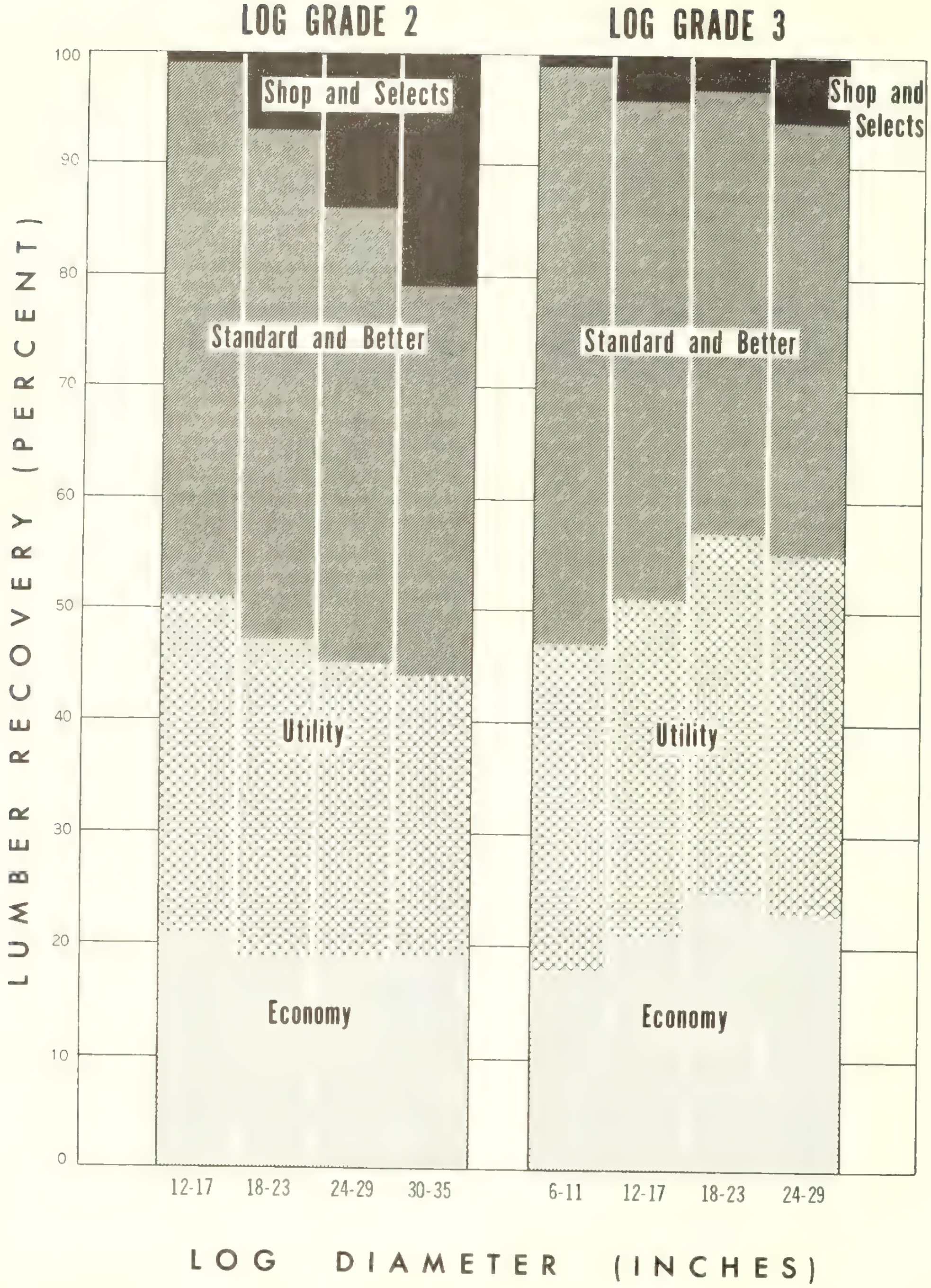

Figure 6.--Surfaced dry lumber grade recovery, by 6-inch diameter classes and by log grades; based on official Bureau log grading and scaling practices.

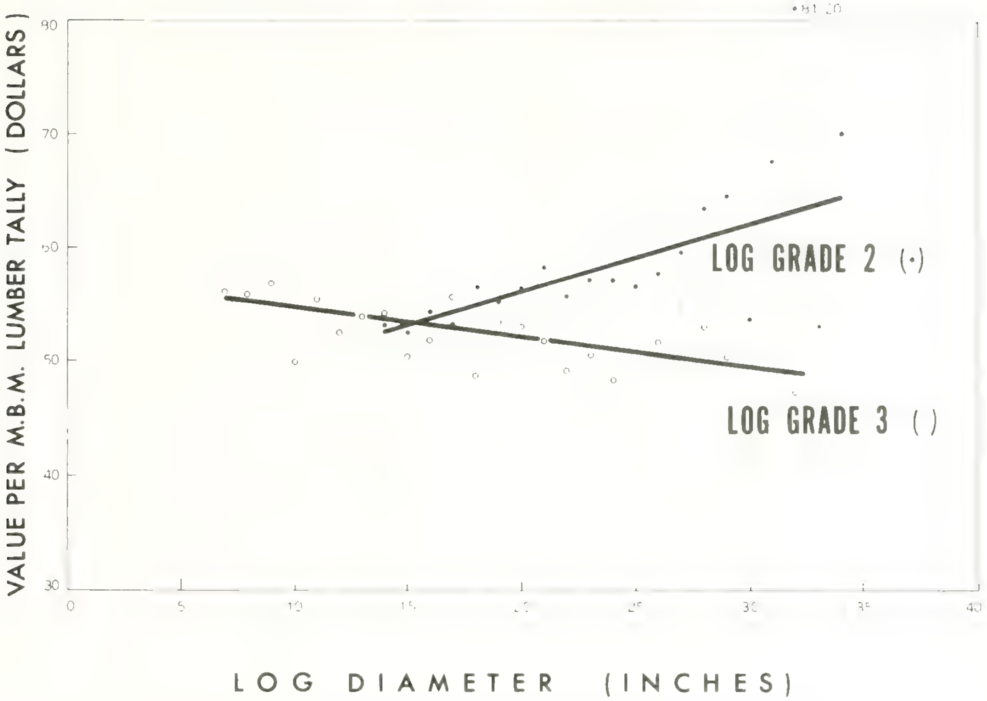

Figure 7.--Relationship of lumber value (dollars per thousand board feet, dry lumber tally basis) to log diameter by log grade (Official Log Scaling and Grading Rules, applied to logs up to 40 feet in length).

When the curves in figure 8 are compared with the lumber value curves in figure 7, the effect of overrun is readily apparent. Generally, the log value curves are considerably higher and have a different form than the curves of lumber value. Although a strong relationship of value and log size was found for log grade 2, the influence of overrun on log value for these logs was so variable that log diameter no longer exerted a significant influence on value. This resulted in an average log value for all diameters, but this unit log value was greater than the highest unit lumber value.

The grade 3 log value curve vividly illustrates the effect of high overruns found in small logs. Figure 7 shows that lumber value decreased at a constant rate from about $55.50 per thousand board feet, lumber tally, for 7-inch-diameter logs, to approximately $49 for 32-inch logs. The change in value on a net log scale basis is considerably different, however. Log value (fig. 8) dropped from about $122.50 for 7-inch logs to approximately $73 per thousand board feet, net log scale, for 32-inch diameters. Four-fifths of this decrease occurred in the 7- to 20-inch diameter range which included the smaller study logs.

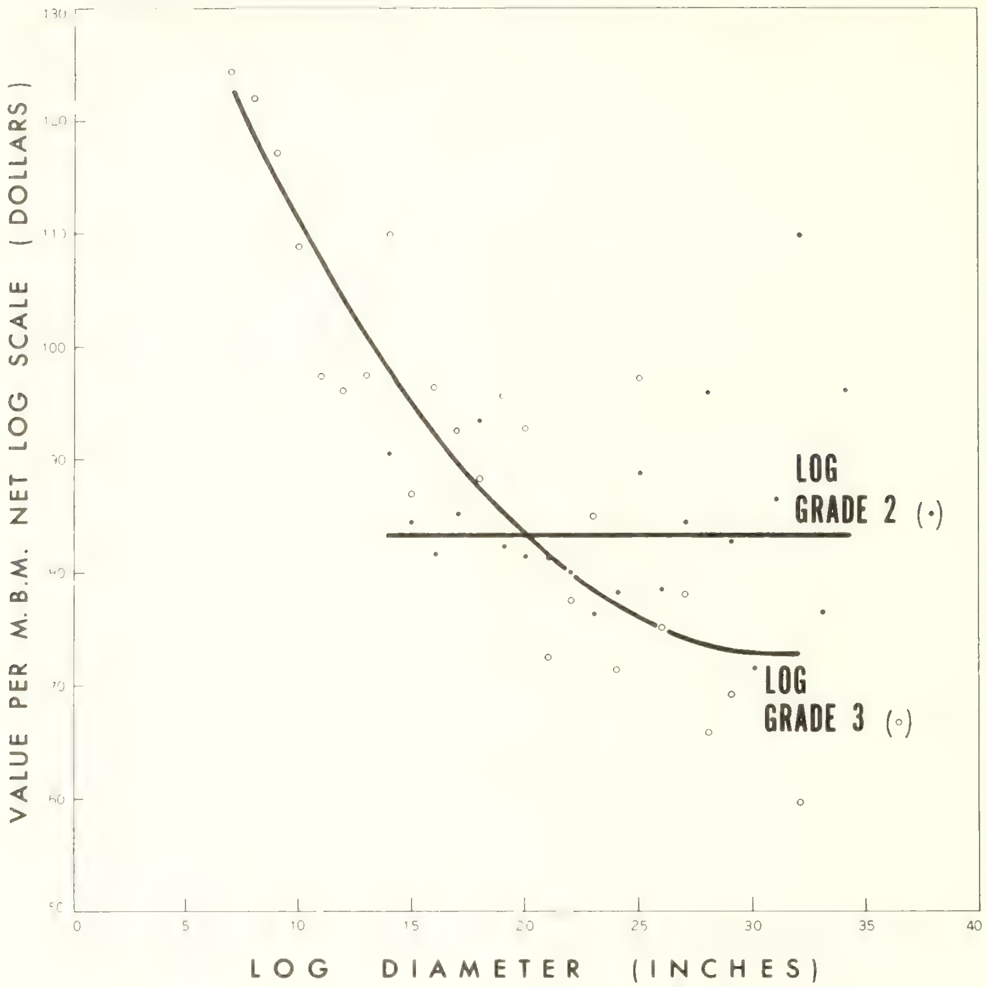

Figure 8.--Relationship of log value (dollars per thousand board feet, net log scale) to log diameter by log grade (Official Log Scaling and Grading Rules, applied to logs up to 40 feet in length).

Overrun by Log Grade

Although overrun is automatically included when product yield is considered in terms of log value (net log scale basis), overruns obtained from the study logs warrant separate consideration. Examination of figure 9 shows the relationship of overrun to log size for log grades 2 and 3. The overrun points plotted for individual diameters for one log grade seem generally intermixed with those of the other grade. Statistical analysis shows, however, that the relationships of overrun to log diameter for the two grades are significantly different. Covariance analysis was used to test for a significant difference in the regression lines.

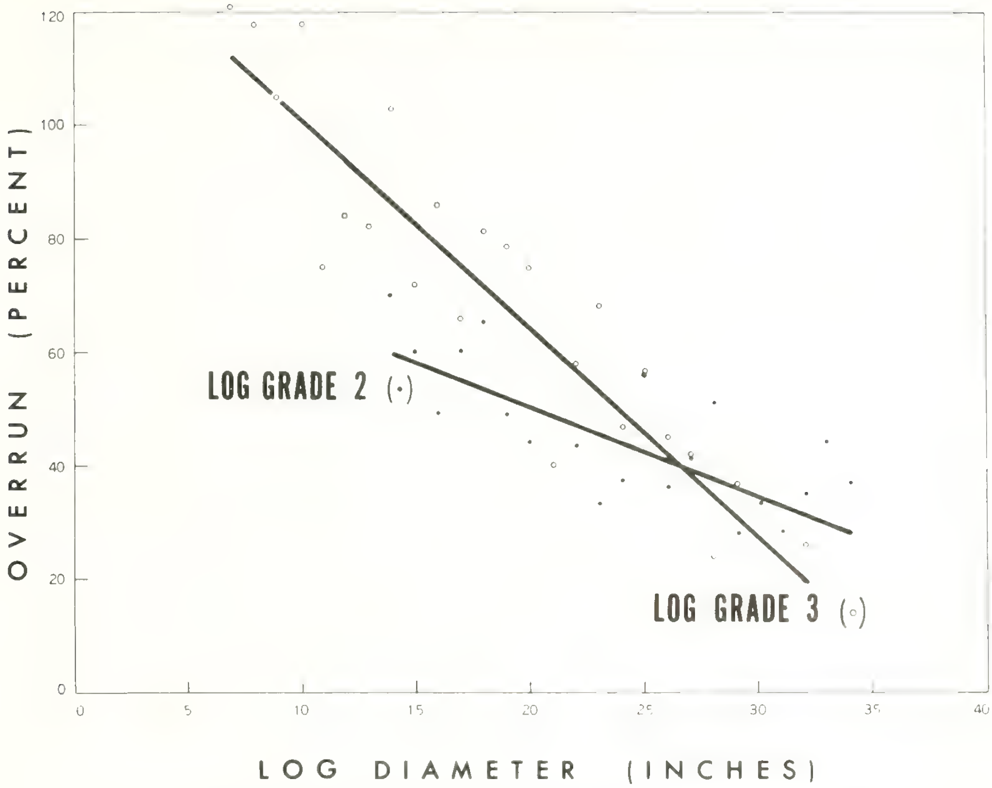

Figure 9.--Relationship of overrun to log diameter by log grade (Official Log Scaling and Grading Rules, applied to logs up to 40 feet in length).

Since a significant difference was found, the two log grade samples are considered to have been drawn from separate populations. The best way to use overrun data from this long-log study utilizing west-side practices is to separate overrun by log grade and log diameter. When the log value curves (fig. 8) based on lumber grade yield and overrun by log grade are used, this separation is effected.

Defect

At first thought, the different overruns observed might seem related to a difference in defect deductions made for the respective log grades. A close look at the plotting of defect deducted for individual diameters (fig. 10) shows the wide variability encountered and a thorough intermixing of points plotted for the two log grades. Regression lines showing the relationship of defect to log size were calculated for each log grade. When covariance analysis was applied, slopes and elevations of the regression lines were not found to be significantly different. As a result, a common regression line for the two log grades was calculated, and the relationship of defect to log size is shown only by the line drawn in figure 10. The relationship is not affected by the log grades sampled in this study.

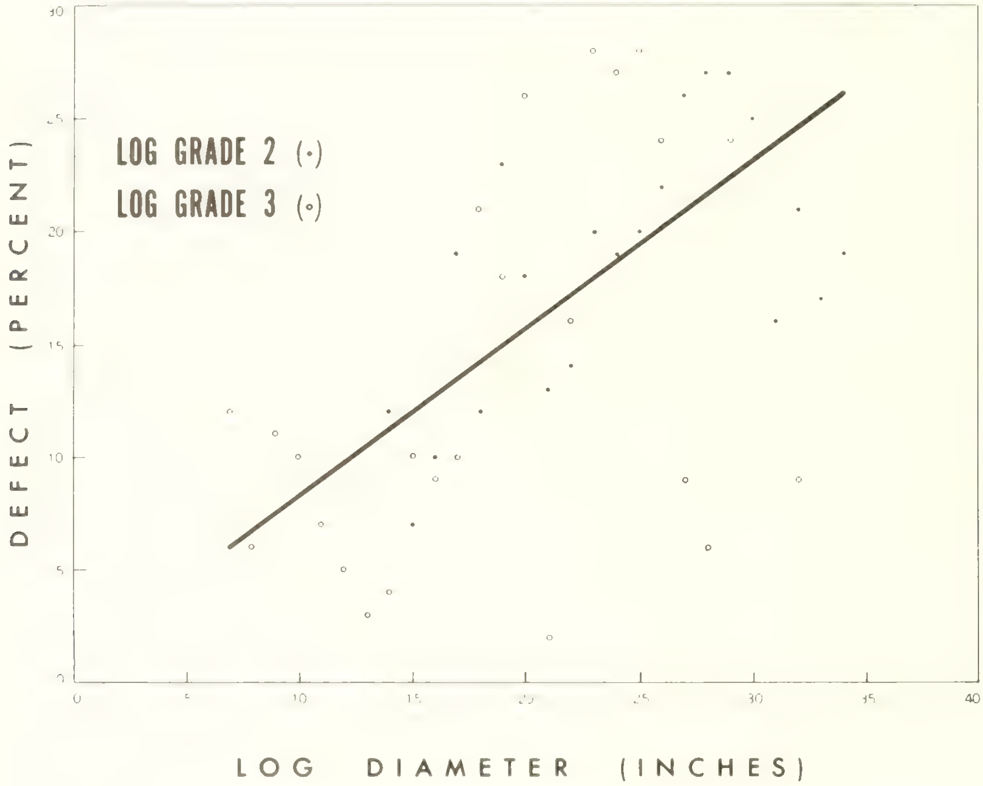

Figure 10.--Relationship of scaled defect to log diameter (Official Log Scaling and Grading Rules, applied to logs up to 40 feet in length).

West-Side Grading and Scaling Rules Applied to Short Logs

Distribution of 520 short logs (up to 22 feet in length) graded and scaled by west-side grading and scaling rules is presented in table 7. Net log scale, total lumber volume, and total lumber value for each log grade-diameter class sampled is included in table 8. This data is the basis for further calculations and analyses presented in table 9 for 6-inch diameter intervals which contained 10 or more logs of a single log grade.

Comparison of table 9 data with that presented in table 6 for long logs illustrates the effect of scaling practice on overrun. When a long log is bucked into shorter lengths for sawing and those short lengths are scaled, the log scale more nearly estimates lumber yield, and overrun is decreased. An example of this is a sound 34-foot log, 16 inches in diameter, with net scale of 340 board

Table 7.--Distribution of 520 white fir short logs, by diameter and log grade; southern Oregon, 1961[1]

Diameter (inches)	No. 1	No. 2	No. 3	Total
	Number			
6- 8	--	--	24	24
9-11	--	--	55	55
12-14	--	16	49	65
15-17	--	58	22	80
18-20	--	49	21	70
21-23	1	50	13	64
24-26	1	40	17	58
27-29	--	47	10	57
30-32	--	23	4	27
33-35	1	16	--	17
36-38	--	3	--	3
Total	3	302	215	520

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[1] Official Log Scaling and Grading Rules for the Puget Sound, Grays Harbor, Southern Oregon, Northern California, and Tillamook County Log Grading and Scaling Bureaus.

NOTE: The heavy lines enclose those log grade—log diameter intervals that are included in table 9. Data from all logs except grade No. 1 are summarized in tables 15 and 16 of the appendix.

Table 8.--Net log scale, total lumber volume, and total lumber value for white fir, by diameter and log grade; southern Oregon, 1961

Log diameter (inches)	Log grade[1]								
	No. 1			No. 2			No. 3		
	Net log scale	Lumber tally	Value	Net log scale	Lumber tally	Value	Net log scale	Lumber tally	Value
	Bd. ft.		Dollars	Bd. ft.		Dollars	Bd. ft.		Dollars
6	--	--	--	--	--	--	--	--	--
7	--	--	--	--	--	--	240	442	24.67
8	--	--	--	--	--	--	370	790	44.34
9	--	--	--	--	--	--	630	1,198	70.14
10	--	--	--	--	--	--	760	1,371	75.05
11	--	--	--	--	--	--	1,330	1,827	102.22
6-11	--	--	--	-- --	--	--	3,330	5,628	316.42
12	--	--	--	--	--	--	1,170	1,813	94.64
13	--	--	--	--	--	--	2,290	3,467	184.44
14	--	--	--	1,660	2,511	136.36	970	1,520	83.42
15	--	--	--	2,480	3,429	181.23	1,040	1,515	73.08
16	--	--	--	3,060	4,166	220.03	930	1,319	68.31
17	--	--	--	3,190	4,419	243.15	1,260	1,839	100.60
12-17	--	--	--	10,390	14,525	780.77	7,660	11,473	604.49
18	--	--	--	2,720	3,955	209.03	1,740	2,566	132.47
19	--	--	--	3,600	5,025	275.94	1,140	1,708	90.21
20	--	--	--	4,200	5,674	318.19	1,650	2,298	112.12
21	230	335	29.68	4,320	5,952	333.94	1,030	1,466	77.09
22	--	--	--	6,620	8,644	483.67	1,630	2,515	130.82
23	--	--	--	3,970	5,230	310.74	790	1,180	59.16
18-23	230	335	29.68	25,430	34,480	1,931.51	7,980	11,733	601.87
24	--	--	--	4,320	5,713	308.91	2,370	3,842	186.92
25	--	--	--	6,840	8,595	490.52	2,060	2,623	129.05
26	370	463	34.33	4,550	5,555	310.17	1,250	1,612	80.89
27	--	--	--	7,700	10,156	584.64	400	595	34.13
28	--	--	--	7,440	9,828	572.59	3,350	4,390	244.50
29	--	--	--	5,540	7,711	483.34	1,150	1,556	82.82
24-29	370	463	34.33	36,390	47,558	2,750.17	10,580	14,618	758.31
30	--	--	--	3,350	5,332	332.13	1,210	1,521	75.66
31	--	--	--	6,820	8,540	485.71	--	--	--
32	--	--	--	2,490	3,328	216.64	1,400	1,793	85.10
33	590	871	91.31	5,000	6,526	406.38	--	--	--
34	--	--	--	2,790	3,596	218.97	--	--	--
35	--	--	--	2,280	3,351	234.09	--	--	--
30-35	590	871	91.31	22,730	30,673	1,893.92	2,610	3,314	160.76
36	--	--	--	770	1,009	68.47	--	--	--
37	--	--	--	1,450	1,869	120.76	--	--	--

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[1] Official Log Scaling and Grading Rules for the Puget Sound, Grays Harbor, Southern Oregon, Northern California, and Tillamook County Log Scaling and Grading Bureaus; applied to short logs, 22 feet or less in length.

Table 9.--Log input, lumber yield, and lumber value for white fir of southern Oregon, based on west-side log grading and scaling practices, 1961[1]

LOG INPUT AND LUMBER YIELD

Item	Log grade and diameter interval							
	No. 2				No. 3			
	12-17	18-23	24-29	30-35	6-11	12-17	18-23	24-29
Logs.....................number..	74	99	87	39	79	71	34	27
Gross log scale.......board feet..	11,420	30,400	47,770	30,150	3,500	8,280	9,750	13,940
Net log scale.........board feet..	10,390	25,430	36,390	22,730	3,330	7,660	7,980	10,580
Defect..................percent..	9	16	24	25	5	7	18	24
Lumber tally..........board feet..	14,525	34,480	47,558	30,673	5,628	11,473	11,733	14,618
Overrun.................percent..	40	36	31	35	69	50	47	38
GRADE YIELD (in percent of dry lumber tally)								
Select:								
C	1	2	2	4	2	1	1	1
D	0	1	2	3	0	0	0	1
Total	1	3	4	7	2	1	1	2
Shop:								
Molding	0	2	3	6	0	0	0	0
All Shop and Outs	0	1	5	6	0	2	2	3
Total	0	3	8	12	0	2	2	3
Common:								
Standard and Better	49	47	41	35	55	46	41	39
Utility	30	28	27	26	27	30	32	32
Economy	20	19	20	20	16	21	24	24
Total	99	94	88	81	98	97	97	95
LUMBER VALUE (in dollars)								
Basis:								
Per M b.m. lumber tally	53.75	56.02	57.83	61.75	56.22	52.69	51.30	51.88
Per M b.m. net log scale	75.15	75.95	75.57	83.32	95.02	78.92	75.42	71.67

[1] Bureau log grades for hemlock, maximum scaling length 40 feet; applied to short logs, 22 feet or less in length.

feet. This log was bucked into a 16-inch, 16-foot log and an 18-inch, 18-foot log whose net scales were 160 and 240 board feet, respectively. A total of 540 board feet of lumber was recovered from these two segments. The short logs thus gave a combined overrun of 35 percent, compared with the 59 percent of overrun calculated from the long-log scale. No scale deductions were made from either the long log or the short logs bucked from it.

From tables 6 and 9, one can generalize that overruns obtained from long logs are higher than those from short logs in the same log grade-diameter class, except in the largest diameters sampled. This is what one would expect, since larger logs have less taper and overrun differences arising from log scaling practice should be smaller.

A broad idea of the effect overrun from short logs has on log value may be gained from table 9. A more complete picture may be obtained by comparing the curves in figure 11 with those in figure 8 for long-log values. Product recoveries on a net log scale basis were found to be consistently less for short logs until log diameters larger than 28 inches were compared.

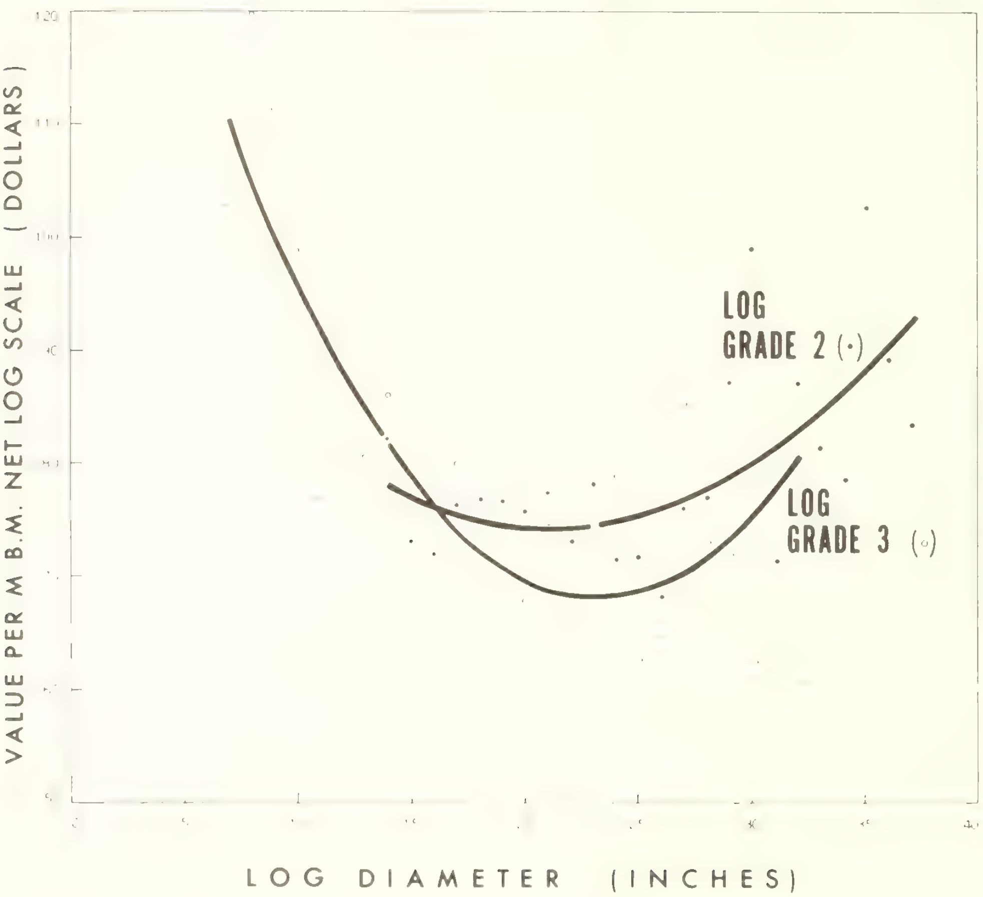

Figure 11.--Relationship of log value (dollars per thousand board feet, net log scale) to log diameter by log grade (Official Log Scaling and Grading Rules, applied to logs up to 22 feet in length).

APPENDIX

Trial Log Grades for Associated Species

Grade 1:

Size: Minimum diameter, 18 inches; minimum length, 12 feet.

Knots: 75 percent surface clear if 16 feet long. Shorter logs shall have 12 feet of 100 percent surface clear length.

Exception: Two pin knots allowed on the surface-clear portions.

Grade 2:

Size: Minimum diameter, 14 inches; minimum length, 12 feet.

Knots: Three types of logs

- a. 20 inch plus logs--
  One clear face and one face which has live and dead knots and indicators not over 1 inch in diameter. The other two faces may have any number of knots of any size.
- b. 17- to 19-inch logs--
  Two clear faces, with 1 pin knot allowable on one of the clear faces.
- c. 14- to 16-inch logs--
  Three clear faces. No pin knots allowed on the clear faces.

Grade 3:

Size: Minimum diameter, 12 inches; minimum length, 12 feet.

Knots: Any number of knots equal to one-sixth of the log diameter or less are permitted, except that one knot only, larger than one-sixth of the log diameter is permitted.

Grade 4:

Size: Minimum diameter 6 inches; minimum length, 8 feet.

Knots: Any number. Any merchantable log which will not grade out 1, 2, or 3, is automatically grade 4.

Explanatory notes:

A face is one-quarter of the log circumference for the full length of the log.

A clear face is one with no knots or knot indicators.

When a knot larger than one-sixth of the diameter occurs in a knot cluster, a decision must be made as to whether the scale or grade of the log will be affected. In such cases the following rules will apply--

- a. Knot clusters or burls affecting the log to considerable width and depth require a scaling deduction and shall not be considered in grading associated species.
- b. Knot clusters that are not large enough to require a scaling deduction shall be treated the same as though the large knot in the cluster was a single knot.

Table 10.--Surfaced dry lumber grade recovery from No. 2 white fir sawmill logs, by 1-inch diameter intervals, east-side practice, southern Oregon, 1961[1/]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C and Better	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchantable	Construction	Standard	Utility	Economy	
		Percent of total recovery													Bd. ft.
18	1	6.7	2.3	5.1	0	0	0.3	0	1.4	4.8	17.9	25.0	24.3	12.2	225
20	1	13.1	8.8	11.9	0.1	1.1	3.9	0.6	3.9	6.3	18.0	17.6	11.6	3.1	364
21	1	12.6	10.0	18.4	0	.2	1.2	.2	5.6	2.9	11.3	16.1	16.2	5.3	336
23	4	4.8	2.9	7.5	0	.1	.5	.1	2.2	6.0	18.8	23.7	22.0	11.4	1,452
26	2	4.9	2.6	2.6	.1	1.5	6.6	1.3	1.5	2.6	11.5	19.3	26.1	19.4	731
28	1	12.0	5.7	11.9	0	.1	.7	.1	3.4	1.7	7.7	13.7	22.7	20.3	463
30	1	11.8	6.2	23.3	.4	2.1	3.6	.5	6.4	1.8	7.4	11.7	14.8	10.0	692
33	1	5.2	3.7	10.0	0	.1	.7	.1	2.9	4.3	15.2	20.3	23.5	14.0	929
34	1	7.9	7.0	25.9	0	.9	3.6	.6	7.4	2.9	9.3	11.5	13.0	10.0	791
35	1	5.9	4.8	3.7	0	0	.2	0	1.5	8.6	19.5	22.1	21.1	12.6	1,009
36	1	.7	.1	.9	0	0	.1	0	.2	3.1	13.2	21.6	32.5	27.6	839

[1/] Trial Log Grades for Associated Species; maximum scaling length, 16 feet.

Table 11.--Surfaced dry lumber grade recovery from No. 3 white fir sawmill logs, by 1-inch diameter intervals, east-side practice, southern Oregon, 1961[1]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C and Better	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchantable	Construction	Standard	Utility	Economy	
		Percent of total recovery													Bd. ft.
12	8	0.9	0	0	0	0	0	0	0	5.0	19.1	27.4	30.6	17.0	757
13	17	1.0	0.2	0.6	0	0	0	0	0.2	5.1	19.0	26.6	29.2	18.1	2,230
14	16	1.0	0	0	0	0	0	0	0	5.5	18.6	26.2	30.3	18.4	2,502
15	21	.9	.2	.6	0	0	0	0	.2	4.1	16.1	24.8	31.9	21.2	3,667
16	17	1.0	0	0	0	0	0	0	0	5.0	18.6	27.0	30.1	18.3	3,389
17	22	1.3	.3	.3	0	0.1	1.7	0.4	.6	4.9	17.1	24.8	28.9	19.6	5,062
18	26	1.3	.4	.6	0	.2	1.2	.3	.3	4.6	17.2	24.9	29.8	19.2	6,949
19	19	1.2	.2	.5	0	0	0	0	.2	5.7	18.2	24.5	28.8	20.7	5,588
20	25	1.2	.6	.9	0	.2	.7	.1	.3	4.6	16.8	24.4	29.4	20.8	7,830
21	12	1.8	1.2	1.2	0	0	.1	0	.4	5.7	19.1	26.2	28.0	16.3	4,104
22	23	1.4	.7	1.7	0	0	.1	0	.5	4.9	16.4	23.0	29.0	22.3	8,865
23	21	1.4	.9	1.7	0	.3	.8	.1	.5	3.9	15.6	23.9	30.3	20.6	9,074
24	16	1.4	.6	1.2	0	.3	1.8	.4	.7	4.0	15.2	22.4	29.5	22.5	6,888
25	20	1.2	.8	.8	0	.2	.6	.1	.4	4.5	16.6	24.3	29.7	20.8	9,564
26	17	1.5	1.0	2.1	0.1	.7	3.1	.7	1.1	3.7	14.3	21.8	28.5	21.4	9,074
27	15	1.2	.7	1.4	.1	.8	2.7	.5	.6	3.7	15.1	23.4	29.4	20.4	8,941
28	22	2.9	2.7	3.8	0	.5	2.1	.4	1.5	4.4	15.2	21.1	25.5	19.9	13,344
29	17	2.8	2.4	3.9	0	.6	2.5	.5	1.5	3.8	14.2	21.0	27.0	19.8	10,001
30	13	2.0	1.3	3.2	0	.4	1.4	.3	1.0	3.7	14.6	22.5	28.9	20.7	9,394
31	5	1.5	1.3	1.5	.1	1.7	5.8	1.0	.9	3.0	12.6	20.5	28.6	21.5	4,014
32	11	2.7	2.6	5.1	.1	1.2	3.3	.5	1.7	2.7	11.6	19.2	27.9	21.4	8,408
33	5	3.0	2.1	6.9	.2	1.2	2.9	.5	2.2	2.4	10.3	17.1	27.5	23.7	3,602
34	5	1.7	1.4	2.0	.2	1.2	1.4	.2	.7	4.0	15.7	23.4	28.6	19.5	4,521
35	1	6.6	10.5	7.8	0	.1	.5	.1	3.2	4.9	14.3	17.8	19.9	14.3	702
36	1	18.0	10.1	28.5	0	.4	1.9	.3	8.0	2.4	7.1	7.7	8.6	7.0	779
37	3	3.3	2.9	3.6	0	0	.2	0	1.2	3.9	14.3	20.4	27.9	22.3	2,929

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[1] Trial Log Grades for Associated Species; maximum scaling length, 16 feet.

Table 12.--Surfaced dry lumber grade recovery from No. 4 white fir sawmill logs, by 1-inch diameter intervals, east-side practice, southern Oregon, 1961[1]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C and Better	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchant-able.	Con-struc-tion	Stand-ard	Utility	Economy	
		Percent of total recovery													Bd. ft.
6	1	1.4	0	0	0	0	0	0	0	12.4	31.4	25.4	16.4	13.0	35
7	8	2.4	0.4	0.4	0	0	0	0	0.1	6.8	19.7	26.0	27.8	16.4	357
8	13	.9	0	0	0	0	0	0	0	5.2	19.8	28.4	29.2	16.5	698
9	14	2.0	.6	.9	0	0	0.1	0	.3	7.0	22.2	28.2	25.7	13.0	925
10	19	1.6	.2	.2	0	0	0	0	0	6.2	19.7	24.7	27.7	19.7	1,589
11	16	1.4	.2	.6	0	0	0	0	.2	6.2	21.0	27.4	27.5	15.5	1,569
12	11	1.1	.1	.5	0	0	0	0	.1	5.2	16.5	24.6	31.2	20.7	1,186
13	4	.6	0	0	0	0	0	0	0	3.2	13.3	21.4	32.2	29.3	622
14	5	.9	.1	.5	0	0	0	0	.1	4.6	18.0	26.5	30.8	18.5	1,018
15	9	1.4	.3	.6	0	0	0	0	.2	3.9	14.3	22.3	31.7	25.3	1,526
16	3	.7	0	0	0	0	0	0	0	3.7	15.9	25.4	32.5	21.8	704
17	3	.8	0	0	0	0	0	0	0	4.8	17.0	23.6	29.6	24.2	666
18	2	.4	0	0	0.1	2.4	16.5	3.8	3.0	2.0	8.8	15.3	25.2	22.5	416
19	2	.6	0	0	0	0	0	0	0	2.5	12.4	22.4	34.8	27.3	566
20	2	.4	0	0	0	0	0	0	0	1.3	8.4	17.9	36.8	35.2	611
21	2	.4	0	0	0	0	0	0	0	1.8	8.6	16.4	35.1	37.7	514
22	3	.5	0	0	0	0	0	0	0	2.0	10.4	19.7	35.2	32.2	1,223
24	1	.6	0	0	0	.6	4.1	.9	.7	2.6	12.4	21.6	31.5	25.0	447
25	2	.6	0	0	0	0	0	0	0	2.7	12.8	22.6	33.9	27.4	887
28	1	.7	0	0	0	.3	.9	.1	0	3.4	16.2	27.4	33.4	17.6	715
31	1	.8	0	0	0	.3	.9	.1	0	3.8	16.7	27.2	33.2	17.0	723

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[1] Trial Log Grades for Associated Species; maximum scaling length, 16 feet.

Table 13.--Surfaced dry lumber grade recovery from No. 2 white fir sawmill logs, by 1-inch diameter intervals, west-side practice, southern Oregon, 1961[1]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchantable	Construction	Standard	Utility	Economy	
		Percent of total recovery													Bd. ft.
14	9	0.9	0.1	0.6	0	0	0	0	0.2	4.8	17.4	25.5	31.1	19.4	3,022
15	8	1.0	0	0	0	0	0	0	0	5.0	17.2	25.5	31.3	20.0	3,179
16	10	1.9	.4	.8	0	0	0	0	.2	5.0	17.7	24.5	28.6	20.9	4,215
17	9	1.2	.4	.1	0	0	0	0	.1	5.2	17.4	24.8	29.7	21.1	3,860
18	6	1.3	.6	.6	0	0.2	0.9	0.2	.4	6.2	20.4	26.1	27.3	15.8	3,333
19	7	1.8	1.2	1.5	0	0	.1	0	.5	5.3	16.9	23.4	28.7	20.6	3,461
20	12	2.1	1.2	2.3	0	.1	.4	.1	.7	4.5	16.5	23.8	28.9	19.4	8,403
21	6	2.1	1.2	3.6	0	.1	.6	.1	1.0	5.3	17.3	23.7	26.9	18.1	4,890
22	13	2.1	1.3	1.8	0	0	.2	0	.6	4.3	16.4	23.9	29.2	20.2	11,290
23	3	1.2	.6	1.0	0.1	1.1	5.3	1.2	1.2	5.0	17.4	23.4	25.5	17.0	2,568
24	4	3.1	2.0	2.3	0	0	.1	0	.8	4.6	15.6	22.5	27.9	21.1	3,795
25	5	1.8	1.1	2.2	0	.7	3.1	.6	.9	4.2	15.6	22.7	27.2	19.9	6,150
26	6	2.2	1.5	3.7	0	.3	1.4	.2	1.2	4.5	15.7	22.4	27.0	19.9	6,772
27	13	2.5	2.2	3.2	0	.5	3.1	.7	1.6	4.4	15.8	22.2	26.1	17.7	15,880
28	4	4.4	3.2	8.1	.1	.7	2.6	.5	2.6	2.7	11.3	18.1	25.7	20.0	5,436
29	4	3.8	3.7	7.3	.1	.7	2.1	.3	2.3	4.1	14.6	20.2	23.5	17.3	4,309
30	5	2.0	1.3	1.1	0	.2	.8	.1	.5	3.5	14.2	22.1	30.6	23.6	7,009
31	5	4.8	3.7	9.5	.2	2.1	6.6	1.1	3.1	2.3	9.9	16.0	23.0	17.7	8,077
32	1	7.4	7.9	20.3	.2	1.5	3.2	.5	6.0	2.6	9.2	12.6	16.0	12.6	1,666
33	2	1.9	2.1	.8	0	0	0	0	.5	3.3	13.6	21.6	31.6	24.6	3,971
34	4	6.6	5.1	8.8	.2	.8	1.4	.2	2.7	4.3	13.7	18.5	22.0	15.7	6,992

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[1] Official Bureau log grades for hemlock; maximum scaling length, 40 feet.

Table 14.--Surfaced dry lumber grade recovery from No 3 white fir sawmill logs, by 1-inch diameter intervals, west-side practice, southern Oregon, 1961[1]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchantable	Construction	Standard	Utility	Economy	
		Percent of total recovery													Bd. ft.
7	9	2.3	0.4	0.3	0	0	0	0	0.1	6.3	19.2	26.0	27.7	17.7	774
8	17	1.7	.4	.4	0	0	0	0	.1	5.6	19.9	26.8	28.1	17.0	1,790
9	13	1.4	.1	.2	0	0	0	0	.1	7.6	22.6	27.3	26.0	14.7	2,096
10	7	.7	.1	.6	0	0	0.1	0	.2	2.8	13.5	23.3	33.7	25.0	1,352
11	12	1.3	.1	0	0	0	0	0	0	6.8	20.5	27.2	28.2	15.9	1,992
12	12	.9	.1	.5	0	0	0	0	.1	4.3	17.0	25.6	30.9	20.6	2,560
13	16	1.0	.1	.3	0	0	0	0	.1	5.1	18.7	26.6	29.6	18.5	5,325
14	8	1.4	.4	.5	0	0.3	2.2	0.5	.6	4.5	16.4	23.7	29.2	20.3	3,085
15	7	.8	.1	.7	0	0	.1	0	.2	3.8	14.9	22.8	30.9	25.7	2,114
16	4	1.0	.5	.3	0	0	0	0	.1	4.1	15.6	24.3	31.4	22.7	2,117
17	6	1.2	.6	2.2	0	.4	3.9	1.0	1.5	4.4	16.0	22.3	26.7	19.8	3,153
18	4	.6	.1	0	0	0	0	0	0	2.8	13.1	22.8	34.4	26.2	2,276
19	2	1.3	.3	.2	0	.7	2.7	.5	.3	4.1	15.8	23.6	29.0	21.5	1,501
20	5	.8	.2	1.0	0.1	.9	2.4	.4	.3	3.9	15.2	22.8	29.6	22.4	3,546
21	3	.9	.3	.2	0	0	0	0	.1	4.1	16.3	24.9	30.9	22.3	2,191
22	4	.7	.3	.1	0	0	0	0	.1	2.9	13.2	22.5	33.6	26.6	2,856
23	4	1.1	.4	1.2	0	.3	1.2	.3	.6	2.9	12.4	20.9	31.6	27.1	3,175
24	5	.7	.2	.4	0	0	0	0	.1	2.9	12.5	20.9	33.5	28.8	4,628
25	2	3.3	3.4	2.2	.3	2.6	7.1	1.3	1.4	3.3	12.1	19.3	25.9	17.8	2,229
26	2	.9	.6	.5	0	.3	.9	.1	.2	3.1	14.2	23.7	32.8	22.7	2,354
27	1	1.0	.1	.7	0	0	.1	0	.2	5.2	19.6	27.7	29.0	16.4	1,503
28	1	.7	0	0	0	.3	.9	.1	0	3.6	16.4	27.3	33.4	17.3	1,438
29	3	.7	.1	.3	.1	.6	1.9	.3	.2	2.6	12.7	22.4	33.6	24.5	4,426
32	1	.6	.1	.4	0	0	0	0	.1	2.4	11.4	20.3	34.5	30.2	1,791

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[1] Official Bureau log grades for hemlock; maximum scaling length, 40 feet.

Table 15.--Surfaced dry lumber grade recovery from No. 2 white fir sawmill logs, by 1-inch diameter intervals, west-side practice, southern Oregon, 1961[1]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchantable	Construction	Standard	Utility	Economy	
		Percent of total recovery													Bd. ft.
14	16	1.0	0.2	0.6	0	0	0	0	0.2	4.9	18.3	26.6	30.5	17.7	2,511
15	18	.8	0	.2	0	0	0	0	.1	4.2	17.3	26.4	32.0	19.0	3,429
16	20	1.3	.2	.4	0	0	0	0	.1	4.7	16.8	24.5	30.4	21.6	4,166
17	20	1.9	.7	.6	0	0	0	0	.2	5.0	17.9	25.3	28.7	19.7	4,419
18	14	1.0	.1	.3	0	0	0	0	.1	4.9	17.4	25.1	30.8	20.3	3,955
19	17	1.3	.3	.6	0	0	0	0	.2	6.2	19.4	25.2	28.1	18.7	5,025
20	18	1.9	1.3	1.7	0	0.2	0.9	0.2	.7	4.5	16.6	23.7	28.5	19.8	5,674
21	16	1.7	1.0	2.3	0	0	.2	0	.7	5.2	17.1	24.1	28.3	19.4	5,952
22	21	1.7	.9	2.1	0	0	.2	0	.6	5.2	17.6	24.0	28.0	19.7	8,644
23	13	2.7	1.8	3.0	0.1	.5	1.3	.2	1.0	4.6	16.8	23.6	27.2	17.2	5,230
24	13	1.2	.7	1.2	0	.2	1.5	.4	.7	4.3	16.1	23.5	29.0	21.2	5,713
25	17	1.7	1.0	1.8	.1	.9	3.4	.7	.9	4.4	16.1	23.4	27.2	18.4	8,595
26	10	1.7	1.2	2.2	0	.2	1.7	.4	1.1	4.4	15.6	22.6	28.4	20.5	5,555
27	18	2.1	1.6	3.3	0	.3	1.9	.4	1.4	4.1	15.4	22.5	27.5	19.5	10,156
28	16	2.3	2.1	2.8	0	.6	2.1	.4	1.1	4.5	15.8	22.0	26.2	20.1	9,828
29	13	3.7	3.1	5.8	0	.8	3.2	.6	2.1	3.6	13.6	20.0	25.2	18.3	7,711
30	7	3.5	2.5	6.8	.1	.5	1.4	.3	2.1	3.4	13.8	21.3	26.7	17.6	5,332
31	11	1.8	1.4	2.9	.1	1.6	5.5	1.0	1.1	2.9	12.2	19.8	27.9	21.8	8,540
32	5	4.9	4.9	7.0	.1	.7	1.2	.2	2.3	3.2	12.6	18.9	25.3	18.7	3,328
33	8	3.4	2.8	8.8	.1	.8	2.1	.4	2.6	2.7	11.2	18.0	26.5	20.6	6,526
34	4	2.6	3.1	3.7	.3	1.5	1.8	.2	1.3	4.2	15.2	21.8	26.1	18.2	3,596
35	4	8.5	5.3	11.1	0	.1	.7	.1	3.3	2.3	9.3	15.0	23.5	20.8	3,351
36	1	5.9	4.8	3.7	0	0	.2	0	1.5	8.6	19.5	22.1	21.1	12.6	1,009
37	2	4.5	4.4	5.5	0	.1	.4	.1	1.9	5.0	16.5	20.8	23.8	17.0	1,869

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[1] Official Bureau log grades for hemlock; maximum scaling length, 22 feet.

Table 16.--Surfaced dry lumber grade recovery from No. 3 white fir sawmill logs, by 1-inch diameter intervals, west-side practice, southern Oregon, 1961[1/]

Log diameter (inches)	Number of logs	Lumber grade													Total lumber tally
		C	D	Molding	Factory Select	No. 1 Shop	No. 2 Shop	No. 3 Shop	Shop Outs	Select Merchant-able	Con-struc-tion	Stand-ard	Utility	Economy	
		Percent of total recovery													Bd. ft.
7	10	2.1	0.3	0.3	0	0	0	0	0.1	6.7	19.6	25.1	27.8	18.0	442
8	14	1.6	.3	.6	0	0	0	0	.2	5.1	19.5	27.9	29.2	15.6	790
9	17	1.4	.3	.3	0	0	0	0	.1	8.0	24.4	28.9	23.9	12.7	1,198
10	17	1.7	.2	.2	0	0	0	0	.1	5.6	19.0	25.8	28.6	18.8	1,371
11	21	1.3	.2	.5	0	0	0	0	.1	5.9	20.7	27.4	28.0	15.9	1,827
12	17	1.1	.1	.5	0	0	0	0	.1	5.0	16.1	23.9	31.4	21.8	1,813
13	23	1.0	.1	.3	0	0	0	0	.1	5.1	17.7	25.4	30.1	20.2	3,467
14	9	1.7	.3	.9	0	0	0.1	0	.3	5.4	18.1	25.0	28.8	19.4	1,520
15	9	.6	0	0	0	0	0	0	0	3.0	12.9	21.7	33.6	28.2	1,515
16	6	1.0	.4	.1	0	0	0	0	.1	4.3	15.6	24.4	31.7	22.4	1,319
17	7	.8	0	.1	0	0.6	6.2	1.6	1.5	4.2	16.0	23.4	27.3	18.3	1,839
18	9	.7	.1	0	0	.4	2.7	.6	.5	3.9	15.1	22.4	30.3	23.3	2,566
19	5	.7	.1	.8	0.1	1.1	3.9	.7	.4	3.2	13.8	22.3	30.2	22.7	1,708
20	7	.7	.2	.7	0	0	.1	0	.2	2.9	12.6	21.3	32.8	28.5	2,298
21	4	.9	.3	.1	0	0	0	0	.1	4.2	16.9	26.0	30.4	21.1	1,466
22	6	1.1	.4	.2	0	.3	.8	.1	.1	3.4	14.8	24.0	32.6	22.2	2,515
23	3	.6	0	0	0	.2	1.5	.3	.3	3.1	13.7	22.9	32.7	24.7	1,180
24	8	.7	.3	.3	0	.1	.5	.1	.2	2.8	12.2	20.6	33.4	28.8	3,842
25	6	.7	.1	.5	0	.1	.3	0	.2	2.8	12.9	22.1	33.2	27.1	2,623
26	3	.8	.5	.6	0	.4	1.2	.2	.2	2.6	12.3	21.6	33.7	25.9	1,612
27	1	.6	.1	.3	.7	6.4	16.7	2.8	.7	1.5	7.7	14.5	25.6	22.4	595
28	7	2.1	1.7	.7	.1	.5	1.1	.2	.4	4.0	15.4	23.7	30.1	20.0	4,390
29	2	.8	.1	.7	0	0	1.0	.3	.4	4.0	16.5	25.5	31.6	19.1	1,556
30	2	.6	0	0	0	.5	1.5	.2	0	2.8	13.0	22.4	33.6	25.4	1,521
32	2	.5	0	0	0	0	0	0	0	2.5	11.9	21.1	34.9	29.1	1,793

[1/] Official Bureau log grades for hemlock; maximum scaling length, 22 feet.

Table 17.--Surfaced dry lumber prices used in calculating values for white fir

Lumber grades		Thickness weighting factor (in percent)	Price per M b.m.	
Developed in study	From WPA summary		From WPA summary[1]	Used in study
4/4 and Thicker C and Better	4/4 C and Better Select	11.34	$157.87	--
	5/4 and Thicker C and Better	88.66	158.63	[2]$158.54
4/4 and Thicker D	4/4 D Select	14.57	122.85	--
	5/4 and Thicker D Select	85.43	133.12	[2]131.62
4/4 and Thicker Molding	4/4 and Thicker Molding Stock	--	122.40	122.40
5/4 Factory Select	5/4 and Thicker Factory Select	--	121.42	121.42
5/4 No. 1 Shop	5/4 and Thicker No. 1 Shop	--	109.77	109.77
5/4 No. 2 Shop	5/4 and Thicker No. 2 Shop	--	78.88	78.88
5/4 No. 3 Shop	5/4 and Thicker No. 3 Shop	--	59.00	59.00
5/4 Shop Outs	4/4 and Thicker Box Lumber	--	46.45	46.45
4/4 Select Merchantable and Construction	4/4 No. 2 and Better Common	7.40	87.58	--
8/4 Select Merchantable and Construction	1-5/8 inch Construction	92.60	70.90	[2]72.14
4/4 Standard	4/4 No. 3 Common	4.38	60.80	--
8/4 Standard	1-5/8 inch Standard	95.62	63.37	[2]63.26
4/4 Utility	4/4 No. 4 Common	3.77	49.03	--
8/4 Utility	1-5/8 inch Utility	96.23	44.22	[2]44.40
4/4 Economy	4/4 and Thicker No. 5 Common	2.75	33.28	--
8/4 Economy	1-5/8 inch Economy	97.25	25.12	[2]25.34

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[1] 1960 average prices for white fir taken from Western Pine Association's annual price summary dated January 9, 1960.

[2] Weighted by lumber thicknesses developed in study.

Pacific Silver Fir

A BIBLIOGRAPHY WITH ABSTRACTS

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and JERRY F. FRANKLIN

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January 1965

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
Philip A. Briegleb, Director Portland, Oregon

FOREST SERVICE U.S. DEPARTMENT OF AGRICULTURE

FOREWORD

This bibliography lists references containing information on Pacific silver fir, *Abies amabilis* (Dougl.) Forbes, in North American and European literature. We have attempted to include all references which might conceivably provide useful information on this species and we would appreciate notification of additional references. Articles are listed alphabetically by author; abstracts are provided for those considered more significant. A subject matter index is given on pages 81 through 83, and a list of common and scientific names of tree species mentioned in the bibliography is found on page 84.

Appreciation is expressed to Miss Marie Gould, librarian at the U.S. Forest Service Library, Portland, Oregon, for obtaining many of the references for examination.

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Pacific silver fir is abundant from 2,500- to 5,000-foot elevation on level benches and gentle north slopes. Common associates are western hemlock, Douglas-fir, and noble fir. Above 4,000 feet, Pacific silver fir often occurs in clusters and open groves. The largest trees vary between 150 to 180 feet in height and 3 to 5 feet in diameter. Foliage is deep green and cones are dark purple in color. Seeds ripen in early October.

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Pacific silver fir is found in two of the coniferous forest communities described as occurring above 3,700-foot elevation on this peak located in the western portion of the central Oregon Cascades. An *Abies amabilis-Tsuga heterophylla* community is best developed on a south slope between 4,000 and 4,400 feet. Hemlock outnumbers silver fir nearly three to one and averages somewhat larger in diameter. Reproduction of both species is present in localities within the stand where the canopy is rather open. Above 4,300 feet, noble fir replaces hemlock and an *Abies procera–A. amabilis* community results. Soils throughout both communities are of medium-to-shallow depth with occasional rock exposures and contain a considerable amount of humus in the A horizon. Floristic descriptions of both communities are included.

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Decay was most pronounced in trees past 80 years of age, and maximum net periodic increment indicated a pathological rotation of 121 to 140 years of age. Local volume tables showing deductions in board and cubic feet by diameter classes are included. No consistent difference in decay percent was evident between fast- and slow-growing trees in the same age classes.

Lists 21 wood-destroying fungi found associated with decay in living trees. Of these the trunk rots *Stereum sanguinolentum*, red heart rot, and *Echinodontium tinctorium*, brown stringy rot, caused 87 percent of the decay. Root and butt rots accounted for 10.8 percent of the total loss-- *Poria subacida* and *Polyporus* [*Polystictus*] *abietinus* were the most prevalent of this group.

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1948. Report of the Forest Service. Year ended December 31st, 1947. 111 pp., illus.

Contains a volume table for mature coast balsam which probably is mainly Pacific silver fir.

66. ________
1950. Report of the Forest Service. Year ended December 31st, 1949. 141 pp., illus.

Preliminary investigations into decay of western hemlock and Pacific silver fir in the Prince Rupert Forest District showed stand losses of 60 and 49 percent in hemlock and Pacific silver fir, respectively. Decay losses averaged 51 and 44 percent in western hemlock and Pacific silver fir trees, respectively.

67. ________
1951. Report of the Forest Service. Year ended December 31st, 1950. 133 pp., illus.

68. ________
1952. Report of the Forest Service. Year ended December 31st, 1951. 153 pp., illus.

The forest associations on the west coast of Vancouver Island were divided into two categories: group A, associations maintained by denuding factors (principally fire) recurring every 300 to 500 years, and group B, associations capable of being maintained in the long-continued absence of denuding factors.

Pacific silver fir is a characteristic species of the latter category and occurs in the dominant canopy of the (1) Deerfern-Three-leaved Collwort-Beech fern Association and (2) the Vaccinium-Moss-Deerfern Association, is capable of attaining dominance in the (3) Vaccinium-Bunchberry Association; and occurs in the lower strata of the (4) Salal-Bunchberry-Sphagnum Association.

69. ________
1953. Report of the Forest Service. Year ended December 31st, 1952. 171 pp., illus.

70. British Columbia Department of Lands and Forests.
1955. Report of the Forest Service. Year ended December 31st, 1954. 147 pp., illus.

71. ———
1957. Report of the Forest Service. Year ended December 31st, 1956. 149 pp., illus.

Contains tables of diameter class net volume factors for coniferous trees with or without visible signs of decay. Coast balsam is presumably mainly Pacific silver fir.

72. ———
1959. Report of the Forest Service. Year ended December 31st, 1958. 125 pp., illus.

73. ———
1960. Report of the Forest Service. Year ended December 31st, 1959. 127 pp., illus.

74. Britton, Nathaniel Lord, and Shafer, John Adolph.
1908. North American trees; being descriptions and illustrations of the trees growing independently of cultivation in North America, north of Mexico and the West Indies. 894 pp., illus. New York: Henry Holt & Co.

75. Brockman, C. Frank.
1933. The forests of Mt. Rainier. Nat. Hist. 33: 523-532, illus.

76. ———
1947. Flora of Mount Rainier National Park. U.S. Dept. Int., 170 pp., illus.

Pacific silver fir is one of the most widely distributed tree species in the park. It is typical of the Canadian Zone and occurs up to the lower limits of the Hudsonian Zone.

77. ———
1949. Conifers of the Cascades. Univ. Wash. Arbor. Bul. 12: 11-13, 31, illus.

A general listing of species and their habitats along the Cascade Range from Mount Baker in Washington to Mount Lassen in California. Pacific silver fir is the dominant true fir in the Cascades near the middle elevations.

78. ———
1949. Trees of Mount Rainier National Park. 49 pp., illus. Seattle: University Washington Press.

"Most widely distributed...and...abundant true fir in the state of Washington...the most common of the true firs in Mount Rainier National Park."

Needles clothe branches thickly, growing from both sides of the twig and along the top as well. Cones are barrel shaped, deep purple in color, 3 to 6 inches long, and about 2-1/2 inches wide. Bark is smooth, ash gray, and distinctly marked with conspicuous chalky areas; it is rarely furrowed and ridged, and, if so, only near the base.

79. Brockman, C. Frank.
1955. Pacific silver fir, *Abies amabilis* (Dougl.) Forbes. Univ. Wash. Arbor. Bul. 18(4): 97, illus.

A general description of the gross botanical characteristics of Pacific silver fir and a comparison of these with the botanical characteristics of common true fir associates that may be confused with it. The role of the beetle, *Pseudohylesinus* sp., in logging Pacific silver fir is mentioned.

Foliage of Pacific silver fir grows from the top as well as the sides of the branches--sometimes hiding the twig--a feature distinguishing it from grand fir whose foliage grows only from the sides of the branch. Pacific silver fir is stomatiferous only on the lower surface of its foliage, whereas noble and alpine fir foliage has stomates on all surfaces. In addition, the individual leaves of noble fir are usually plump or angular in cross section while the leaves of silver fir are flat.

The cones of Pacific silver fir are deep purple in color, cylindrical, and 3-1/2 to 6 inches long. Subalpine fir cones, though purple, are smaller and different in shape; grand fir cones are green and smaller; noble fir cones are larger, columnar in form, and their overlapping green bracts extend from between the cone scales, covering the cones.

80. Browne, J. E.
1962. Standard cubic-foot volume tables for the commercial tree species of British Columbia, 1962. Brit. Columbia Forest Serv., 107 pp.

81. Brush, Warren D.
1945. Silver fir, *Abies amabilis* (Dougl.) Forb. Amer. Forests 51: 498-499, illus.

A general description of the species and its silvical characteristics.

82. Brydon, James E., Dore, William G., and Clark, John S.
1963. Silicified plant asterosclereids preserved in soil. Soil Sci. Soc. Amer. Proc. 27: 476-477, illus.

Tests with plant material of several species including Pacific silver fir indicated that only Douglas-fir yielded opal particles resembling those found in a soil on Vancouver Island.

83. Buchanan, T. S.
1940. Fungi causing decay in wind-thrown Northwest conifers. Jour. Forestry 38: 276-281.

An evaluation of the fungi causing decay in timber windthrown in 1921 and examined in 1926, 1929, and 1936. Pacific silver fir was examined only in 1926. At that time, it had the greatest variety of sporophores on a higher percentage of trees (99 percent) than any of the other species, and 54 percent of Pacific silver fir cubic-foot volume was lost. Of the three most important fungi, *Fomes pinicola* was present on 70 percent of the trees, decaying 28 percent of the volume; *F. applanatus* on 49 percent of the trees, decaying 33 percent of the volume; *Polyporus abietinus* on 48 percent of the trees, decaying 14 percent of the volume.

84. Buchanan, T. S.
1948. *Poria weirii:* Its occurrence and behavior on species other than cedars. Northwest Sci. 22: 7-12.

85. __________ and Englerth, G. H.
1940. Decay and other volume losses in wind-thrown timber on the Olympic Peninsula, Wash. U.S. Dept. Agr. Tech. Bul. 733, 30 pp., illus.

A continuation of Boyce's study (cf. ref. 41). The results are practically the same.

86. __________ and Englerth, G. H.
1943. Deterioration of Olympic wind thrown timber. Timberman 44(8): 24, 26, 28, 30, illus.

Popularized version of the information presented in the U.S. Dept. Agr. Tech. Bul. 733.

87. Buckhorn, W. J., and Lauterbach, Paul G.
1957. Timing of aerial surveys for the balsam woolly aphid.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 142, 2 pp.

88. __________ and Orr, P. W.
1959. Forest insect conditions in the Pacific Northwest during 1958.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 41 pp., illus.

89. __________ and Orr, P. W.
1959. Forest insect conditions in the Pacific Northwest during 1959.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 37 pp., illus.

90. __________ and Orr, P. W.
1961. Forest insect conditions in the Pacific Northwest during 1960.* U.S. Forest Serv. Pacific NW. Forest & Range Expt. Sta., 40 pp., illus.

91. __________ and Orr, P. W.
1962. Forest insect conditions in the Pacific Northwest during 1961.* U.S. Forest Serv. Region 6, 41 pp., illus.

92. Buckland, D. C., Foster, R. E., and Nordin, V. J.
1949. Studies in forest pathology. VII. Decay in western hemlock and fir in the Franklin River area, British Columbia. Canad. Jour. Res. C, 27: 312-331, illus.

An investigation of decay in true firs (primarily Pacific silver fir) and western hemlock in the Juan de Fuca forest region on southern Vancouver Island, B. C. *Poria subacida* accounted for 17.7 percent, *Armillaria mellea* 6.6 percent, and *Fomes annosus* 3.0 percent of the infections occurring in the fir, all three as root or butt rots. *Poria weirii* caused 2.2 percent of the infections in western hemlock but none in the fir. *Fomes pinicola* was the most important trunk rot, accounting for 19.7 percent of all infections. Other organisms occurring in the trunk and their percent of all infections were: *Stereum abietinum*, 15.1 percent, and *Hydnum abietis*, 5.6 percent. In fir, trunk infections were 53.0 percent of the total, root and butt infections 41.9 percent, and sap rots 5.1 percent. Almost two-thirds of the infections entered through scars.

In terms of loss through decay, *Fomes pinicola* was most important, causing 40.5 percent of the total decay volume in fir. *Hydnum abietis* was next in importance, causing 12.1 percent, and *Poria subacida* was third with 11.5 percent. *Fomes pini*, of importance in western hemlock stands, was a minor cause of loss in fir.

Studies of decay in relation to age showed fir to be a shorter lived tree than western hemlock. Below 300 years of age, fir was more resistant than hemlock, but beyond that age incidence of decay was greater in fir, all trees over 400 years old being infected. Tables showing the relation between age and volume of decay are also included. Decay volume goes from 0 percent at 75 years to 11.3 percent at 275 and 39.6 percent at 375 years. The relation of decay to diameter is also tabulated and plotted. Attempts to relate decay to rate of growth were not successful.

Actual volumes of fir utilized by a logging company in the area were 84 percent of the average gross board-foot volumes to a 10-inch top, or 89 percent of the net volume. Losses other than through decay were mostly top breakage in fir.

93. Buell, Edward D.
1938. Forest statistics for Clatsop County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 11 pp., illus.

94. ____________
1941. Forest statistics for Polk County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 83, 14 pp., illus.

95. Buffam, P. E.
1962. Observations on the effectiveness and biology of the European predator *Laricobius erichsonii* Rosen. (Coleoptera: Derodontidae) in Oregon and Washington. Canad. Ent. 94: 461-472, illus.

96. Burden, F. P., Naden, G. R., and Caverhill, P. Z.
1928. Forests and forestry in British Columbia. Brit. Columbia Dept. Lands Forest Branch, 33 pp., illus.

97. Burns, Findley.
1911. The Olympic National Forest: Its resources and their management. U.S. Dept. Agr. Forest Serv. Bul. 89, 20 pp., illus.

Pacific silver fir is generally confined to the western and southern portions of the forest, where it grows in two silvicultural types: the foothill or lower type and the upper-slope or subalpine type. Pacific silver fir and grand fir are estimated to comprise 15 percent of the total merchantable timber in the forest.

98. Canada Department of Agriculture.
1942. Twenty-first annual report of the Canadian plant disease survey, 1941. 102 pp.

Poria weirii is reported killing Pacific silver fir at elevations of 3,000 to 4,000 feet near Youbou, B. C.

99. Canada Department of Interior.
1917. Canadian woods for structural timbers. Forestry Branch Bul. 59, 44 pp., illus.

100. Canada Department of Mines and Resources.
1941. Report of the lands, parks and forest branch for the fiscal year ended March 31, 1940. Ann. Rpt., pp. 60-135.

101. Canada Department of Northern Affairs and National Resources.
1956. Strength and related properties of woods grown in Canada. Forestry Branch Forest Prod. Lab. Tech. Note 3, 7 pp.

102. Canada Department of Resources and Development Forestry Branch.
1951. Canadian woods--their properties and uses. Ed. 2, 367 pp., illus. Ottawa: Edmond Cloutier, King's Printer and Controller of Stationery.

103. Canada Dominion Forest Service.
1961. Native trees of Canada. Canada Dept. Mines and Resources, Dominion Forest Serv. Bul. 61, ed. 6, 291 pp., illus.

104. Carl, G. Clifford, Guiguet, C. J., and Hardy, George A.
1952. A natural history survey of the Manning Park area, British Columbia. Brit. Columbia Provisnl. Mus. Occas. Papers 9, 130 pp., illus.

105. Carlberg, G. L., and Kurth, E. F.
1960. Extractives from the western true firs. TAPPI 43: 982-988, illus.

Extractives from Pacific silver fir, noble fir, white fir, and grand fir were comparatively examined for their composition in an attempt to find differences on which to base a distinquishing chemical test. No distinguishing differences were found in the extractives from the wood of these species. Paper chromatography indicated that only Pacific silver fir may have a component that is different from the other species.

106. Carpenter, Stanley Barton.
1961. A description of the Pacific silver fir-hemlock forest on the western slopes of the Cascade Mountains in the vicinity of Mount Rainier, Washington. 55 pp., illus. Unpublished M. S. thesis on file at Univ. Wash.

An analysis of five forest community types occurring in the Mount Rainier area. Types are segregated on the basis of elevation, species composition, and stand structure.

Pacific silver fir is present mainly as an understory species in the Canadian-Humid Transition Zones between 3,000 and 3,500 feet. The dominant tree species in this area are western hemlock, western redcedar, and sometimes Douglas-fir. Soils are deep and of good quality. Litter accumulates to depths of 3 to 4 inches. At 3,500 to 4,000 feet, Pacific silver fir and western hemlock dominate the stand canopy; silver fir also dominates the understory, although hemlock is present. Alaska-cedar, noble fir, and Douglas-fir are present as minor components. Soil characteristics and litter depths are approximately the same. From 4,000 to 4,600 feet, the forest stands are composed almost entirely of Pacific silver fir. Occasional specimens of subalpine fir, mountain hemlock, and Alaska-cedar are scattered through the stand, and western hemlock occurs sparsely in the understory. The soils are shallow podsols and the litter layer is 4 to 5 inches deep. From 4,600 to 5,000 feet, the forests gradually become more open, resembling those found in the Hudsonian Zone. Pacific silver fir is present but does not dominate. Western white pine, Alaska-cedar, Douglas-fir, mountain hemlock, and subalpine fir are present. The soils are extremely shallow; no organic layer is present. Meadow vegetation is found between and under the scattered trees.

107. Ceballos y Fernández de Córdoba, Luis.
1958. Los abetos del mundo. Montes (Madrid) 14(80): 91-102, illus.

Contains generalized distribution maps of some of the world's more commercially important species of true firs, Pacific silver fir included.

108. Chamberlin, Willard Joseph.
1918. Bark beetles infesting the Douglas-fir. Oreg. Agr. Col. Expt. Sta. Bul. 147, 40 pp., illus.

109. Chamberlin, W. J.
1958. The Scolytoidea of the Northwest; Oregon, Washington, Idaho and British Columbia. 208 pp., illus. Corvallis: Oregon State College.

110. Chang, Ying-Pe.
1954. Bark structure of North American conifers. U.S. Dept. Agr. Tech. Bul. 1095, 86 pp., illus.

111. Childs, T. W., and Clark, J. W.
1953. Decay of wind-thrown timber in western Washington and northwestern Oregon. U.S. Bur. Plant Indus. Forest Path. Spec. Release 40, 20 pp., illus.

Graphs and tabulated data provide information on rates of decay in wind-thrown Douglas-fir, Sitka spruce, western hemlock, and Pacific silver fir. Pacific silver fir decays rapidly compared with associated species.

112. Chittenden, F. J., ed.
1931. Conifers in cultivation: the report of the conifer conference held by the Royal Horticultural Society. 634 pp., illus. London: Royal Horticultural Society.

Contains listings of the largest trees of each species planted in Britain and the important books on the subject published between 1553 and 1931.

Contains many pieces of information concerning the relative success of Pacific silver fir in many parts of Great Britain, the history of its identification by early botanists, and its economic value.

113. Clark, Donald H.
1946. Methods for processing secondary species for wood shingles. Jour. Forestry 44: 878-880.

Pacific silver fir shingles treated with a combination of urea, dimethylolurea, and a plasticising agent, may compete successfully with other roofing materials.

114. Clifford, N.
1957. Timber identification for the builder and architect. 141 pp., illus. London: Leonard Hill Ltd.

115. Coleman, W.
1889. On conifers. Jour. Roy. Hort. Soc. London 11: 320-339.

Remarks on the selection of coniferous species, sites and planting procedures, and general horticultural information for establishing pinetums. Pacific silver fir is mentioned as a suitable species.

116. Collingwood, G. H., and Brush, Warren D.
1955. Knowing your trees. New and rev. ed., 328 pp., illus. Washington, D. C.: American Forestry Association.

117. Coltman-Rogers, Charles.
1920. Conifers and their characteristics. 333 pp., illus. New York: The Macmillan Co.

118. Condon, Thomas.
[n. d.] The forest trees of Oregon. II, III. West. Amer. Sci. 7: 115-117; 142-143.

119. Cooke, M. C.
1905. Fungoid pests of forest trees. Jour. Roy. Hort. Soc. London 29: 361-391.

Silver fir cluster-cups are discussed on p. 386. *Aecidium pseudo-columnare* (Kuhn), known in Great Britain as *Peridermium columnare*, occurs on Pacific silver fir in Britain and Germany.

120. Cooke, Wm. Bridge.
1962. On the flora of the Cascade Mountains. Wasmann Jour. Biol. 20: 1-67.

A comparison of the floras of Mount Baker, Mount Rainier, Mount Mazama (Crater Lake), Mount Shasta, and Mount Lassen. Pacific silver fir is found on the first two mountains listed.

121. ________ and Shaw, Charles Gardner.
1952-53. The Suksdorf fungus collections. Wash. State Col. Res. Studies 20: 135-145; 21: 3-57.

The following fungal species were collected on Pacific silver fir: *Hypoderma robustum* v. Tub., *Lophodermium consociatum* Darker, *Corticium radiosum* Fr.

122. Cooper, W. S.
1957. Vegetation of the Northwest-American province. Pac. Sci. Cong. Proc. 8(4): 133-138.

123. Coulter, W. K.
1954. Silver fir beetles *(Pseudohylesinus)*. NW. Forest Pest Leaflet 1, 4 pp. [unnumbered]. Portland, Oreg.: Industrial Forestry Association.

124. ________ and Hunt, John.
1953. Progress report; *Pseudohylesinus* bark beetles in silver fir in the State of Washington, 1949-1952. U.S. Bur. Ent. Plant Quar. Forest Insect Lab. unpublished office rpt., 24 pp., illus. Portland, Oreg.

A discussion of the severe damage to mature and overmature Pacific silver fir trees in mixed stands caused by an association of bark beetles, *Pseudohylesinus granulatus* Lec. and *P. grandis* Sw., and parasitic fungi, principally *Armillaria mellea*. It appears that the fungus assists the beetles in overcoming the host resistance and providing favorable food for developing larvae; the insects provide the fungus with avenues of entry into the tree and are a partial means of dispersal. The success of this association appears related to host vigor. Effectiveness of control by salvage logging is limited, and increased utilization of the timber resource is stressed.

Other fungi found associated with the bark beetles are: *Fomes annosus*, *Poria weirii*, and *Poria subacida*.

125. Cowlin, R. W., Moravets, F. L., and Forest Survey Staff.
1937. Timber volume and type acreage on the national forests of the North Pacific Region, from the inventory phase of the forest survey. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Res. Notes 22, 6 pp. plus 10 tables, illus.

126. Cox, William T.
1911. Reforestation on the national forests. Pt. 1--Collection of seed. Pt. 2--Direct seeding. U.S. Dept. Agr. Forest Serv. Bul. 98, 57 pp., illus.

127. Currier, Raymond A.
1963. Compressibility and bond quality of western softwood veneers. Forest Prod. Jour. 13(2): 71-80.

Compressibility and panel thickness during hot pressing and after reconditioning were determined for Pacific silver fir veneer bonded with interior blood glue and exterior phenolic glue. Bond quality was ascertained by standard test methods.

128. Curtis, Carlton C., and Bausor, S. C.
1943. The complete guide to North American trees. 337 pp., illus. New York: New Home Library.

129. Dallimore, W., and Jackson, A. Bruce.
1948. A handbook of Coniferae including Ginkgoaceae. Ed. 3, 682 pp., illus. London: Edward Arnold & Co.

130. Darker, Grant Dooks.
1932. The Hypodermataceae of conifers. Arnold Arboretum Contrib. 1, 131 pp., illus.

The following rusts have been found on Pacific silver fir: *Hypoderma robustum* v. *Tubeuf*, *Hypodermella punctata*, sp. nov., *Hypodermella abietis-concoloris* (Mayr) Dearn., *Lophodermium uncinatum*, sp. nov., *Lophodermium autumnale*, sp. nov., *Lophodermium consociatum*, sp. nov.

131. Davidson, J.
1931. The flora of British Columbia. Jour. Roy. Hort. Soc., London 56: 201-206.

132. Davidson, John, and Abercrombie, Ivy.
1927. Conifers, junipers and yew: gymnosperms of British Columbia. 72 pp., illus. London: T. Fisher Unwin Ltd.

133. Davidson, John G. N.
1961. A nutritional study of grand fir and amabilis fir in the greenhouse. Unpublished M. S. thesis on file Univ. Brit. Columbia, 177 pp., illus.

The effects of deficiencies of nitrogen, phosphorus, potassium, calcium, magnesium, and sulphur on the growth and development of Pacific silver fir and grand fir seedlings were studied. These deficiencies caused a significant reduction of growth of both species, except in the low sulphur treatment which was probably contaminated. Deficiencies of these elements affected the root/shoot and foliage/stem ratios and produced a reduction in the total moisture content.

Foliage analyses revealed that in each case the total concentration of the deficient element was much reduced. The grand fir foliage concentrations were consistently higher than for amabilis fir and were influenced more greatly by the treatments.

Each deficiency produced a different visual effect. These were documented photographically, chiefly in color. The actual colors of symptoms were not specific, but the patterns generally were. Diagnostic keys to the deficiency symptoms were prepared. Magnesium and phosphorus symptoms were very distinctive, potassium and calcium were usually so, and nitrogen was the least. An unreported type of calcium deficiency symptom was observed and described.

No single criterion expressed the net result of any treatment. Deficiency symptoms changed with time. In general, it was observed that grand fir is more sensitive to deficiencies than amabilis fir.

134. Day, W. R.
1957. Sitka spruce in British Columbia; a study in forest relationships. Gt. Brit. Forestry Comn. Bul. 28, 110 pp., illus.

135. Dick, James.
1960. A direct seeding of Pacific silver fir.* Weyerhaeuser Co. Forestry Res. Center Forestry Res. Note 33, 4 pp.

An experimental seeding of endrin-treated Pacific silver fir and Douglas-fir seeds and untreated Pacific silver fir seeds resulted in significantly greater stocking of Douglas-firs. There were no significant differences between treated and untreated Pacific silver fir seed in stocking of plots.

In order to obtain equivalent quantities of viable seed per acre, Pacific silver fir seed was sown at the rate of 7 pounds per acre whereas Douglas-fir was sown at the rate of 0.57 pound per acre. Although Pacific silver fir seed costs less, the greater quantity of seed made direct seeding of Pacific silver fir six times more expensive than seeding of Douglas-fir.

136. Dickson, F.
1927. A study of heart-rot in the amabilis fir *(Abies amabilis)* in the Upper Fraser region of British Columbia. Unpublished report of the Dept. Bot., Univ. Brit. Columbia, 44 pp.

A severely suppressed stand of Pacific silver fir, growing beneath Engelmann spruce in the Aleza Lake district of British Columbia, was heavily infected with *Echinodontium tinctorium.* Out of the 502 trees examined, 57.7 percent (17.4 percent of the total volume) were defective. Branch stubs were the most frequent infection courts; other injuries usually served to increase the rate of the longitudinal spread of the rot. The number of defective trees and the volume of rot increased with age. No trees below 120 years of age showed infection.

Suggested control measures: heavy cutting of Pacific silver fir in timber sales, burning of infectious debris, and fire-girdling of all standing defective trees to prevent further production of sporophores.

137. Dimock, Edward J., II.
1958. Silvical characteristics of Pacific silver fir.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Silvical Series 4, 12 pp., illus.

Summarizes the habitat conditions and life history of Pacific silver fir.

138. Dimpflmeier, R. von.
1957. Winterfrostshäden 1955/56 im forstlichen Exotenversuchsgelände Grafrath. Forstwiss. Centbl. 76: 174-187, illus.

Pacific silver fir suffered light needle damage from severe frosts. Many other species, including other true firs, were more heavily damaged.

139. Dixon, Dorothy.
1961. These are the champs. Amer. Forests 67(1): 40-46, 48-50, illus.

The largest Pacific silver fir known is 245 feet tall, is 26 feet 3 inches in circumference, has a crown spread of 54 feet, and is located in the Olympic National Park, Washington.

140. Dodwell, Arthur, and Rixon, Theodore F.
1900. Olympic Forest Reserve, Washington. U.S. Geol. Survey 21st Ann. Rpt. 1899-1900, Pt. 5, Forest Reserves: 145-208, illus.

Contains brief general descriptions of the location and boundaries of the reserve and its natural and cultural features. Data on forest conditions and timber volumes, which make up the greater portion of the article, are presented by townships. Maps indicating tree species distributions on the reserve are included.

The reserve was heavily forested up to 3,000-foot elevation. The total volume of timber in the reserve was 37,100 million board feet. Distribution of the volume by species was estimated as follows: western hemlock, 42 percent; Douglas-fir, 26 percent; Pacific silver fir, 15 percent; western redcedar, 10 percent; and Sitka spruce, 7 percent. Pacific silver fir was found at considerable elevations in the reserve but rarely below 1,500 feet.

141. __________ and Rixon, Theodore F.
1902. Forest conditions in the Olympic Forest Reserve, Washington. U.S. Geol. Survey Prof. Paper 7, 110 pp., illus.

Pacific silver fir comprised 18 percent of the total volume of timber on the reserve and was second only to western hemlock in abundance. It was found everywhere except on the immediate coast of the Pacific Ocean and on the highest mountains. It was not found in commercial amounts below 1,500 feet. Average height was 164 feet and average diameter was 35 inches.

142. Douglas-fir Second-Growth Management Committee.
1947. Management of second-growth forests of the Douglas-fir region. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 151 pp., illus.

143. Douglass, Bernard S.
1960. Collecting forest seed cones in the Pacific Northwest.* U.S. Forest Serv. Region 6, 21 pp., illus.

A popular guide to cone collecting in the Northwest which includes information on identification of cones, collection period and cone testing, selection of parent trees, methods of collection, and care of cones after collecting. Cutting tests of Pacific silver fir cones should be made by slicing the cone lengthwise about one-fourth to one-half inch to one side of the core. Seed quality is measured by the percent of exposed seeds that are sound, 50 percent or more constituting a good average.

144. Dowden, Philip B., and Crosby, David.
1958. The present status of the balsam woolly aphid in the United States. Tenth Internatl. Cong. Ent. Proc. (1956) 4: 823-825.

145. Duffield, John W., and Eide, Rex P.
1959. Polyethylene bag packaging of conifer planting stock in the Pacific Northwest. Jour. Forestry 57: 578-579.

146. Dümmer, R. A.
1913. The conifers of the Lindley Herbarium; Botany School, Cambridge. Jour. Roy. Hort. Soc. London 39: 63-91.

147. Dunn, Malcolm.
1892. Statistics of conifers in the British Islands. Jour. Roy. Hort. Soc. London 14: 481-571.

Lists the largest specimens of introduced conifers by counties with their dimensions, health, and the soil condition in which they are growing. Pacific silver fir is listed in many counties.

148. __________
1892. The value in the British Islands of introduced conifers. Jour. Roy. Hort. Soc. London 14: 73-102.

California red fir was widely distributed in Britain from 1850 onwards as the "*Abies amabilis* of Douglas" and is known in many places by that erroneous name.

149. Dyer, E. D. A.
1963. Attack and brood production of ambrosia beetles in logging debris. Canad. Ent. 95: 624-631, illus.

150. Eades, H. W.
1932. British Columbia softwoods, their decays and natural defects. Canada Dept. Int. Forest Serv. Bul. 80, 126 pp., illus.

151. __________
1958. Differentiation of sapwood and heartwood in western hemlock by color tests. Forest Prod. Jour. 8(3): 104-106.

Application of the colorimetric agents, perchloric acid, iron, salts, and the pH indicators bromcresol green and bromphenol blue, showed that true firs (Pacific silver and grand firs) possess a high proportion of sapwood as does western hemlock.

152. Ebell, L. F., and Schmidt, R. L.
1961. The influence of meteorological factors upon dispersal of coniferous pollen on Vancouver Island, British Columbia. Canada Dept. Forestry Pub. 1036, 28 pp., illus.

A three-season record is presented of pollen dispersal characteristics of Douglas-fir and associated species and of meterorological data collected along an elevational transect. The study centered upon the relationship between temperature and the production and maturation of male cones. The temperature records indicated a possible relationship between high July temperatures and the dispersion of pollen in abundance the following year by Douglas-fir, mountain hemlock, and the three species of true firs (grand fir, Pacific silver fir, and subalpine fir).

The most favorable weather for pollen dispersal occurs when a high pressure system prevails over the area; and the most unfavorable conditions are associated with low pressure systems and frontal activity. The duration of pollen release is greatly influenced by current weather conditions.

153. Ebell, Lorne F., and Schmidt, Ralph L.
1960. Effect of elevation and climatic factors on production and dispersal of coniferous tree pollen. (Abs.) Soc. Amer. Foresters Proc. 1959:39.

154. Edlin, H. L.
1944. British woodland trees. 182 pp., illus. London: B. T. Batsford Ltd.

Pacific silver fir has been grown as a part tree in Britain since 1830 but has little potential there as a forest tree.

155. Eis, Slavoj.
1962. Statistical analysis of several methods for estimation of forest habitats and tree growth near Vancouver, B. C. Univ. Brit. Columbia Faculty Forestry Bul. 4, 76 pp., illus.

156. Eliot, Willard Ayres, and McLean, G. B.
1938. Forest trees of the Pacific coast. New ed., 565 pp., illus. New York: G. P. Putnam's Sons.

A dendrological reference which provides a description of the range of the species as well as information on the silvics.

157. Elliott, Simon B.
1912. The important timber trees of the United States. A manual of practical forestry. 382 pp., illus. Boston and New York: Houghton Mifflin Co.

158. Elwes, Henry John, and Henry, Augustine.
1909. The trees of Great Britain & Ireland. v. 4, pp. 713-1000, illus. Edinburgh: Privately printed.

159. Empire Forestry Association.
1962. The Commonwealth Forestry handbook, 1962. Ed. 8, rev., 142 pp. London: Empire Forestry Association.

160. Engelhardt, N. T.
1957. Pathological deterioration of looper-killed western hemlock on southern Vancouver Island. Forest Sci. 3: 125-136, illus.

After the second year, decay fungi rapidly penetrated western hemlock trees and reduced the saw log volume below the point of economic recovery by the fifth year. The most important decay-causing fungus was *Fomes pinicola* (Sw.) Cooke, which accounted for 56 percent of the infections and 81 percent of the decay. An examination of a few looper-killed Pacific silver firs revealed a deterioration rate equal to that of western hemlock.

161. Engelmann, George.
1878. A synopsis of the American firs. Acad. Sci. Trans. St. Louis 3: 593-602.

The article attempts to subdivide the genus *Abies* using leaf structure and length of bracts.

Engelmann, after examining foliage specimens from various botanical collections, believed that trees cultivated from some of Douglas' Oregon seeds under the name *A. amabilis* are variety *densiflora* of *A. grandis*. (See next reference).

162. __________
1882. Notes on western conifers. Bot. Gaz. 7: 45.

"*Abies amabilis* (Douglas) Forbes, is not a variety of *A. grandis* as I had assumed, but a very distinct species peculiar to the higher mountains of the Cascade Range from Oregon to British Columbia. It is easily recognized by its dense, dark-green, glossy leaves, very white underneath, usually emarginate, but on the fertile branchlets acute; by its large very thick purple cones and oblanceolate acuminate bracts."

163. English, Edith Hardin.
1951. The flowering season on Mount Baker. Univ. Wash. Arboretum Bul. 14(3): 8-12.

164. __________
1958. Plant life of the area surrounding Glacier Peak. Mountaineer 51(4): 28-39

165. Engstrom, W. H.
1953. Oregon cone crop, 1953.* Oreg. State Bd. Forestry Res. Note 13, 6 pp., illus.

166. __________
1954. Oregon cone crop, 1954.* Oreg. State Bd. Forestry Res. Note 16, 7 pp.

167. Faull, J. H.
1934. The biology of Milesian rusts. Jour. Arnold Arboretum 15: 50-85.

An account of the biology of the fern rusts belonging to the genus *Milesia* including a list of hosts. True firs serve as alternate hosts for these fern rusts, although the various rust species do not appear very host specific. Successful inoculations of *Milesia fructuosa* have been made on many firs including Pacific silver fir, white fir, and California red fir. Some of these rusts are a potential hazard to natural regeneration of true firs and kill or reduce the growth of seedlings and saplings associated with rust-infected ferns.

168. Ferguson, J. W.
1939. How to identify Oregon trees. Oreg. State Bd. Forestry, 15 pp.

169. Ferré, Y. de.
1952. Les formes de jeunesse des Abiétacées. Ontogénie-phylogénie. Toulouse Univ. Lab. Forest. Trav., tome 2, v. 3, art. 1, 284 pp., illus.

170. Flett, J. B.
1922. Features of the flora of Mount Rainier National Park. U.S. Dept. Int. Natl. Park Serv., 50 pp., illus.

Pacific silver fir is sometimes called larch by lumbermen. It is generally present in the park between elevations of 2,000 and 4,000 feet.

171. Forbes, James.
1839. Pinetum Woburnense: or a catalogue of coniferous plants in the collection of the Duke of Bedford at Woburn Abbey. 226 pp., illus. London.

A compilation of brief botanical descriptions and notes of various conifers accompanied by detailed colored drawings of cone, cone scale, leaf, seed, and branchlet specimens. Contains one of the earliest botanical descriptions of Pacific silver fir. The accompanying drawings of cone, branchlet, leaves, etc., are not botanically accurate. The cone, though of correct genus and size, is incorrectly colored brown instead of purple. The leaves and branchlet resemble those of *Picea* not *Abies*. It appears that the drawing was made from mixed specimens of *Abies* and *Picea*.

172. Forest Soils Committee of the Douglas-fir Region.
1957. An introduction to forest soils of the Douglas-fir region of the Pacific Northwest. Various paging, illus. Seattle: University Washington.

173. Foster, R. E., Browne, J. E., and Foster, A. T.
1958. Studies in forest pathology. XIX. Decay of western hemlock and amabilis fir in the Kitimat region of British Columbia. Canada Dept. Agr. Pub. 1029, 37 pp., illus.

Measurements of decay incidence and degree are collated with gross volumes of western hemlock and Pacific silver fir logs in two sample areas described by their vegetative associations: (1) the "fern" association, western hemlock–Pacific silver fir–beech fern–oak fern, and (2) the "moss" association, western hemlock–Pacific silver fir–tall blue bilberry–moss. There was no significant difference between the associations in the amount of decay. However, western hemlock reached its best regional development in the fern association, and Pacific silver fir attained its best regional development in the moss association. In both associations, hemlock and fir had a history of early suppression and temporary releases during the first 100 years of their growth.

A tree decadence classification was applicable to both hemlock and Pacific silver fir and indicated average volumetric losses of approximately 6, 36, and 82 percent for residual, suspect, and dead trees, respectively. Generally, decay increased and net volume decreased with increasing age and diameter. However, subsamples indicated that older surviving trees per se do not necessarily contain less sound wood than younger trees. Approximately 16 percent of the Pacific silver fir was scarred, 70 percent of the scar occurring in the bottom 16 feet of the boles.

Echinodontium tinctorium E. & E. was the most important fungus found attacking living Pacific silver fir, accounting for 41 percent of the infections and 65 percent of the decay. *Fomes pini* (Thore ex Fr.) Karst. was found in 8 percent of the infections and caused 13 percent of the decay. Other white rots found, in order of relative importance, are: *Hericium* sp., *Stereum sanguinolentum* A. & S. ex Fr., *Fomes annosus* Fr., *Poria subacida* (Pk.) Sacc., *Polyporus tomentosus* Fr., and *Armillaria mellea* (Vahl. ex Fr.) Quil. Brown cubical rots found on fir and listed in order of their relative importance are: *Stereum abietinum* Pers., *Fomes pinicola* (Sw.) Cke., and *Polyporus sulphureus* Bull. ex Fr.

174. Foster, R. E., Thomas, G. P., and Browne, J. E.
1953. A tree decadence classification for mature coniferous stands. Forestry Chron. 29: 359-366, illus.

Individual trees in varying stages of susceptibility to and deterioration by wood-destroying fungi can be classified by the presence or absence of visible abnormalities indicative of decay. The classification was composed of: suspect trees, living trees with one or more abnormalities indicative of decay; residual trees, living trees with no abnormality indicative of decay; and dead trees.

Of 102 Pacific silver firs from the Kitimat region, 28 percent of the residual, 63 percent of the suspect, and 100 percent of the dead trees contained defects. These were associated with 13.1 percent decay in the residual class, 37.7 percent decay in the suspect, and 100 percent decay in the dead trees.

175. Foster, R. E., and Ziller, W. G.
1952. Forest disease survey, British Columbia. Canada Dept. Agr. Forest Insect and Disease Survey. Ann. Rpt. 1951: 147-154, illus.

Decay losses in Pacific silver fir are not excessively high--they approach an average cull factor of 30 percent. However, only the younger age and small diameter classes are entirely free from defect. The Indian paint fungus, *Echinodontium tinctorium* Ellis and Everh. and *Fomes pini* (Thore) Lloyd caused 55 and 17 percent of the total decay.

176. Franco, João do Amaral.
1949. Notas nomenclaturais. Soc. Broteriana (Coimbra) B., (ser. 2) 23: 159-176. [In Portugese.]

Took up the name *Abies grandis* for the species universally known as *A. amabilis* and published the new name *A. excelsior* for the species known as *A. grandis*.

177. ___________
1950. Abetos. Anais Inst. Superior Agron. vol. 17, 260 pp., illus.

178. Franklin, Jerry F.
1961. A guide to seedling identification for 25 conifers of the Pacific Northwest.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 65 pp., illus.

Contains information on the seedling characteristics of Pacific silver fir up to the age of 1 year.

179. Franklin, Jerry F.
1963. A proposed physiographic subdivision of the true fir-hemlock forests of the Pacific Northwest. (Abs.) Northwest Sci. 37: 159.

180. ______
1964. Color of immature cones of several Pacific Northwest conifers. Forest Sci. 10: 103-104.

Pacific silver fir growing in the Cascade Range of Oregon and Washington has been observed to produce immature cones of two colors, green and red. The red form is more abundant. Color variation occurs in the cone bracts; thus, it can only be observed when the cones are very young.

181. ______
1964. Douglas' squirrels cut Pacific silver fir cones in the Washington Cascades. U.S. Forest Serv. Res. Note PNW-15, 3 pp., illus.

Observations in the Washington Cascade Range during 1962 indicate the Douglas' squirrel directly affects both present and future seed crops of Pacific silver fir. Squirrels harvest cones by cutting the entire cone-bearing twig rather than by cutting the cone pedicel. As a result, some of the next year's cone buds are removed with the present year's cones.

182. ______ and Trappe, James M.
1963. Plant communities of the northern Cascade Range: a reconnaissance. (Abs.) Northwest Sci. 37: 163-164.

Pacific silver fir is a major climax species in both the *Abies amabilis-Tsuga mertensiana* and *Abies amabilis-Tsuga heterophylla* zones along much of the crest and through the western North Cascades. Pacific silver fir is a timberline species along the westernmost parts of the North Cascades.

183. Frye, Theodore C., and Rigg, George B.
[n.d.] Northwest Flora. 453 pp. Seattle: University Washington.

184. Fulling, Edmund H.
1934. Identification, by leaf structure, of the species of *Abies* cultivated in the United States. Torrey Bot. Club Bul. 61: 497-524, illus.

Fulling prepared a key to species of *Abies* using leaves from sterile branches and a series of photomicrographs of leaf cross sections. He extensively reviewed the literature concerning the anatomical specificity of leaf structure and examined structural variation of particular species. Fulling concluded, at least in regard to those characters necessary for identification, that structural variation is negligible. The "procedure section" of the article fully describes sources and selection of material and methods and techniques of material preparation.

Abies amabilis: "Stomata abundant only on lower surface...hypodermal layer more or less continuous, only an occasional cell or two lacking along upper surface,...leaves not stomatiferous on upper surface."

185. Gannett, Henry.
1902. The forests of Oregon. U.S. Geol. Survey Prof. Paper 4, 36 pp., illus.

186. __________
1902. The forests of Washington; a revision of estimates. U.S. Geol. Survey Prof. Paper 5, 38 pp., illus.

187. Garman, E. H.
1963. Pocket guide to the trees and shrubs of British Columbia. Brit. Columbia Forest Serv. Pub. B 28 (ed. 3, rev.), 137 pp., illus.

188. Gedney, Donald R., and Mayer, Carl E.
1956. Forest statistics for Hood River County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 125, 28 pp., illus.

In 1954, the net volume of live Pacific silver fir sawtimber and growing stock inventoried on commercial forest land in Hood River County, Oregon, was 399 million board feet (Scribner) and 113 million cubic feet, respectively.

189. __________ and Spada, Benjamin.
1958. Forest statistics for Wasco County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 127, 33 pp., illus.

In 1954, the net volume of live sawtimber and growing stock of Pacific silver fir in Wasco County was estimated as 54 million board feet (Scribner) and 32 million cubic feet, respectively.

190. __________ and Twerdal, Melvin P.
1956. Forest statistics for Klickitat County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 124, 27 pp., illus.

191. Gibson, Henry H.
1913. American forest trees. 708 pp., illus. Chicago: Hardwood Record.

192. Gildemeister, E.
1916. The volatile oils. Ed. 2, v. 2, 686 pp., illus. Miltitz near Leipzig: Schimmel and Co.

193. Gilkey, Helen M., and Powell, Garland M.
1961. Handbook of Northwest flowering plants. Ed. 2, rev., 414 pp., illus. Portland, Oreg.: Binfords & Mort.

194. Gill, L. S.
1935. Arceuthobium in the United States. Conn. Acad. Arts Sci. Trans. 32: 111-245, illus.

The dwarfmistletoe, *Arceuthobium campylopodum*, was reported on Pacific silver fir.

195. Gordon, George.
1875. The Pinetum: Being a synopsis of all the coniferous plants at present known, with descriptions, history and synonyms and a comprehensive systematic index. Ed. 2, 484 pp. London: Henry G. Bohn.

196. Gorman, M. W.
1907. Vegetation of the northeast slope of Mount Baker. Mazama 3: 31-48.

Pacific silver fir is present as a minor species below 1,000-foot elevation, is common between 1,000 and 4,000 feet, and, with mountain hemlock, is the most abundant species at 4,000 to 5,000 feet. It is not found above 5,500 feet. Forest line is at 5,000 feet, tree line at 6,700 feet, and timberline at 6,600 feet.

197. ________
1920. The flora of Mount Hood. Oreg. Out-of-Doors 1: 64-96.

198. Graham, Kenneth.
1945. The current outbreak of defoliating insects in coast hemlock forests of British Columbia. Part III. Considerations of chemical control. Brit. Columbia Lumberman 29(4): 38-39, 60, 62, 64, 118, 120, 122, 124, 126, illus.

199. Gratkowski, H. J.
1956. Windthrow around staggered settings in old-growth Douglas-fir. Forest Sci. 2: 60-74, illus.

A detailed study of wind behavior in eight staggered settings on the H. J. Andrews Experimental Forest and of factors affecting wind damage to reserve stands and individual trees.

Windfirmness of species is one of the factors affecting reserve stands. In this study, western redcedar was found to be the most windfirm species followed by Douglas-fir, western hemlock, and Pacific silver fir. Hemlock and silver fir were mainly in the protected understory and, therefore, their root systems were not adapted to withstand the wind stresses which occur on the clear cut perimeters.

200. Great Britain Department of Scientific and Industrial Research.
1957. A handbook of softwoods. Gt. Brit. Dept. Sci. Indus. Res. Forest Prod. Res. Bd., 73 pp. London: Her Majesty's Stationery Office.

A general description of the woods, their mechanical and working properties, uses, durability, resistance to insect attack, botanical ranges, and synonyms. Pacific silver fir is included.

201. Green, George Rex.
1933. Trees of North America (exclusive of Mexico). v. 1, The conifers. 186 pp. Ann Arbor: Edward Bros., Inc.

General dendrological and silvical characteristics of forest trees. A good reference for synonyms and common names of tree species.

202. Griffith, B. G.
1934. A pocket guide to the trees and shrubs of British Columbia. Brit. Columbia Forest Branch, 108 pp.

203. Gruenfeld, J. J., Wright, Ernest, and Coulter, W. K.
1956. Operation counterattack. Timberman 57(12): 92-93, illus.

A general account of the silver fir beetle infestation that began in 1947 in Skagit County, Washington, and the salvage operations that followed it.

The beetles, assisted by shoestring root rot fungus, killed 528 million board feet of timber between 1950 and 1953. In 1954, the infestation covered 652,000 acres but it subsided to 115,000 by 1955. Subsequent deterioration studies indicated that killed trees must be salvaged within 4 years to yield a 50-percent lumber recovery and a 70-percent pulp recovery.

204. Haddock, Philip G.
1961. Coniferous shade trees in suburban development. 37th Natl. Shade Tree Conf. Proc.: 147-159.

205. ———
1961. New data on distribution of some true firs of the Pacific Coast. Forest Sci. 7: 349-351.

Describes the discovery and verification of the occurrence of Pacific silver fir growing in the Marble Mountains of Siskiyou County, California.

206. Hale, J. D.
1932. The identification of woods commonly used in Canada. Canada Dept. Int. Forest Serv. Bul. 81, 48 pp., illus.

207. Halliday, W. E. D.
1937. A forest classification for Canada. Canada Dept. Mines & Resources Forest Serv. Bul. 89, 50 pp.

Pacific silver fir is an important component of the southern, central, and northern sections of the coast forest.

208. ——— and Brown, A. W. A.
1943. The distribution of some important forest trees in Canada. Ecology 24: 353-373, illus.

In Canada, Pacific silver fir is a Pacific coast species. "Amabilis fir is a western American coast radiant that for the most part evidently survived south of the ice during the Wisconsin glaciation and re-invaded northwards." Originally, it spread from southern Beringia in the D-interglacial period.

209. Hansbrough, J. R.
1934. Occurrence and parasitism of Aleurodiscus amorphus in North America. Jour. Forestry 32: 452-458, illus.

Pacific silver fir is a host of this weakly parasitic fungus.

210. Hansen, Carl.
1892. Pinetum Danicum. Jour. Hort. Soc. London 14: 257-480.

Lists the scientific names of various coniferous species and the early botanists who described them, contains accounts of their discoveries by botanists, and describes species habitat and wood characteristics.

Abies amabilis had been described in various publications by Forbes, Engelmann, Sargent; called *Pinus amabilis* by Douglas, *Picea amabilis* by Loudon, *Pinus grandis* by Lambert, and *Abies grandis* var. *densiflora* by Engelmann.

The species was discovered along with noble fir by David Douglas on September 7, 1825, in the Cascades, south of the Grand Rapids of the Columbia River. Douglas called the first species *Pinus amabilis* because of its lovely appearance, and the other species *Pinus nobilis*, a noble tree. Although most of Douglas' specimens were lost in various mishaps during his long explorations, he was able to preserve a few which were taken to England.

In 1833, Dr. Lindley transferred *P. nobilis* and *P. grandis* to *Abies* in the "Penny Cyclopaedia." In 1839, Forbes cited all three species under the generic name of *Abies* in "Pinetum Woburnense" and published the name *Abies amabilis*.

Many botanists, visiting the Northwest, did not see the amabilis fir, although Jeffrey in 1856 reported seeing it in the Fraser River region. Subsequently, botanists, who catalogued the species, tired of relying upon the statements of Douglas and Jeffrey and began to ignore the species. Engelmann believed that the specimens of Douglas and Jeffrey were mixed and that amabilis fir was a fictitious species. In 1880, Engelmann, Sargent, and Parry, on an extended exploration of the Pacific Northwest, rediscovered the species on Silver Mountain, near Fort Hope, Fraser River, between 4,000- and 5,000-foot elevation. Several weeks later, Sargent again found amabilis fir just south of the Columbia River Cascades near the area where Douglas first saw the species. Subsequently, in 1885 and 1889, Mr. and Mrs. Lemmon explored the region and reported that it contained more species of fir than any other known region--*Abies grandis*, *A. amabilis*, *A. nobilis*, and *A. lasiocarpa* (arranged by increasing elevation).

211. Hansen, Henry P.
1940. Paleoecology of two peat bogs in southwestern British Columbia. Amer. Jour. Bot. 27: 144-149, illus.

212. ________
1941. Further pollen studies of post Pleistocene bogs in the Puget lowland of Washington. Torrey Bot. Club Bul. 68: 133-148, illus.

213. ________
1941. Paleoecology of a bog in the spruce-hemlock climax of the Olympic Peninsula. Amer. Midland Nat. 25: 290-297, illus.

214. ________
1942. A pollen study of lake sediments in the lower Willamette Valley of western Oregon. Torrey Bot.Club Bul. 69: 262-280, illus.

215. ________
1943. A pollen study of two bogs on Orcas Island, of the San Juan Islands, Washington. Torrey Bot. Club Bul. 70: 236-243, illus.

216. ________
1944. Further pollen studies of peat bogs on the Pacific Coast of Oregon and Washington. Torrey Bot. Club Bul. 71: 627-636, illus.

217. ________
1947. Postglacial forest succession, climate, and chronology in the Pacific Northwest. Amer. Phil. Soc. Trans. v. 37, pt. 1, 130 pp., illus.

A monographic presentation of the results of a series of pollen analyses of sediments obtained from lakes and bogs throughout the Pacific Northwest. Summarizes most of the preceding references by Hansen.

Due to the similarity of the *Abies* pollen-grain size-frequency distributions, Hansen was not able to accurately distinguish between species so referred to them collectively as the balsam firs. Generally, they were poorly represented in the sedimentary columns, and their "pollen profiles present little that suggests trends of succession or that can be correlated with the interpreted succession of other species."

218. Hansen, Henry P.
1950. Pollen analysis of three bogs on Vancouver Island, Canada. Jour. Ecol. 38: 270-276, illus.

219. ________
1955. Postglacial forests in southcentral and central British Columbia. Amer. Jour. Sci. 253: 640-658, illus.

220. ________ and Mackin, J. Hoover.
1949. A pre-Wisconsin forest succession in the Puget Lowland, Washington. Amer. Jour. Sci. 247: 833-855, illus.

221. Hanzlik, E. J.
1914. The distinguishing features of the true firs *(Abies)* of western Washington and Oregon. Soc. Amer. Foresters Proc. 9: 272-277, illus.

Describes the differences between the bark, leaves, cones, and cone bracts of noble fir, Pacific silver fir, grand fir, and alpine fir.

222. ________
1925. A preliminary study of the growth of noble fir. Jour. Agr. Res. 31: 929-934, illus.

223. ________
1925. A site classification scheme for the western Cascades forest region. Univ. Wash. Forest Club Quart. 4(1): 5-8.

Hanzlik suggests that the various tree species segregate according to site quality. Only Douglas-fir, western hemlock, Sitka spruce, Port-Orford-cedar, and western redcedar are found on site 1, for example. Pacific silver fir occurs on sites 2, 3, 4, and 5. Hanzlik contends that since all species yield about the same in pure stands on the same site, the Douglas-fir site tables can be used for sites 1, 2, and 3 and western hemlock and Pacific silver fir curves used for site 4 and site 5, respectively. According to this scheme, there is no site 1 for Pacific silver fir, noble fir, mountain hemlock, etc., since these are species not found in the best sites in the region.

224. ________
1932. Type successions in the Olympic Mountains. Jour. Forestry 30: 91-93.

Hanzlik describes forest succession in terms of stages in those areas on the western and southern slopes of the Olympic Mountains where fire or windthrow has not occurred for 500 or more years. Stage 1 begins with the establishment of an even-aged, dense Douglas-fir forest following some natural catastrophe. As the

Douglas-fir stand grows older, its dense crown canopy opens slightly and western hemlock becomes established as an understory type. When the Douglas-fir overstory is 300 to 350 years old, the individual trees begin to accrue high-quality growth, although the forest itself is beyond optimum development. The understory hemlocks are of all sizes and ages up to 200 to 250 years old. Stage 2 begins at this time with the appearance of Pacific silver fir as understory type to both hemlock and Douglas-fir. Mortality begins to noticeably reduce the dominant Douglas-fir crown density. Hemlock gradually fills in the crown space formerly occupied by the Douglas-fir and becomes a codominant as well as a suppressed species. Stage 3 commences when the Douglas-firs, now about 500 to 600 years of age, are widely scattered and comprise only a small number of trees compared with the aggregate. However, they probably contain upwards to 50 percent of the merchantable volume. The hemlock, advanced in age and being much shorter lived, also declines. Pacific silver fir responds very well to release and fills in the openings created by the mortality of its two predecessors. In the final stage, Douglas-fir and hemlock occupy a very small portion of the crown canopy or are entirely lacking, and an uneven-aged stand of Pacific silver fir dominates the area. Unless some form of catastrophe substantially opens up the stand, Pacific silver fir will occupy any small openings and continually reestablish itself, thereby excluding the other species.

225. Hanzlik, E. J.
1936. Amount, growth and yield of pulp species on the Olympic Peninsula. Pac. Pulp & Paper Indus. 10(5): 27.

226. Hanzlik, Edward J.
1928. Trees and forests of western United States. 128 pp., illus. Portland, Oreg.: Dunham Printing Co.

Brief descriptions of forest tree species and their growth and of western forest regions and National Forests, keys, and forest statistics. The botanical range of Pacific silver fir extends from southern Alaska southward on both sides of the Cascades to the vicinity of Crater Lake. The species is found at sea level only in Alaska and British Columbia--elsewhere, its altitudinal range is between 1,000 and 5,000 feet, and occasionally 6,000 feet.

In the northern Cascades, Pacific silver fir volume averages 40,000 to 50,000 board feet per acre. Pacific silver fir regenerates entirely by seed; and seedlings endure heavy shade, but thrive in the open wherever soil and atmospheric moisture conditions are sufficient. The wood is soft, easily workable, light in weight, and is used primarily for pulp; it is also suitable for boxes, interior finish, and sash and door stock. The Indian paint fungus, *Echinodontium tinctorium*, is the principal rot--primarily of trees over 200 years of age.

227. Hardin, James W.
1960. Workbook for woody plants. 131 pp., illus. Minneapolis: Burgess Publishing Co.

228. Harding, A.
1892. Conifers at Orton Longueville. Jour. Hort. Soc. London 14: 67-71.

229. Harkness, Bernard.
1949. Conifers at Rochester, New York. Univ. Wash. Arboretum Bul. 12(4): 26, 27, 34.

230. Harlow, W. M.
1934. The dendrology of the more important trees of the United States. Pt. 2, Softwoods. Ed. 3, 69 pp., illus. Ann Arbor: Edward Bros.

231. Harlow, William M., and Harrar, Ellwood, S.
1958. Text book of dendrology. Ed. 4, 561 pp., illus. New York: McGraw-Hill Book Co., Inc.

A general dendrological reference covering the commercial species of North America, written primarily for a beginning student in forestry. A general description of the botanical and silvical features and range of Pacific silver fir is included.

232. Harris, J. W. E.
1960. The balsam woolly aphid, *Adelges piceae* (Ratz), in British Columbia, 1959. Canada Dept. Agr. Div. Forest Biol. Bimo. Prog. Rpt. 16(2): 3-4.

233. Harshberger, J. W.
1911. Phytogeographic survey of North America. Die Vegetation der Erde, Bd. 13, 790 pp., Leipzig.

234. Hartmann, F. K., Querengässer, F., and Jahn, G.
1953. Unterlagen für den anbau westamerikanischer nadelholzarten in Deutschland. Allg. Forst-u. Jagdztg. 125: 25-48.

Lists the various Pacific Northwest tree species and provides notes on their geographic distribution, climatic, soil, and light tolerances, growth rates, common forest tree associates, wood characteristics, and suitability for planting in Germany. Pacific silver fir appears suitable for planting in the best mountain drainage sites.

235. Harvey, Athelstan George.
1947. Douglas of the fir. 290 pp., illus. Cambridge: Harvard University Press.

Discloses (pp. 58-60) how Douglas named *Abies amabilis* and *Abies nobilis* during an expedition in the Cascades south of the Columbia River. Subsequently, the existence of *Abies amabilis* was doubted by botanists until an expedition by Dr. Engelmann, Parry, and Sargent traced Douglas' old route and rediscovered the species.

236. Hayes, G. L.
1959. Forest and forest-land problems of southwestern Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 54 pp., illus.

Pacific silver fir occurs in southwestern Oregon but is considered commercially unimportant.

237. Hedgcock, George Grant.
1912. Notes on some diseases of trees in our national forests. II. Phytopathology 2: 73-80.

Pacific silver fir is attacked by *Polyporus schweinitzii* Fr. and *Echinodontium tinctorium* E. & E.

238. Hedgcock, George Grant.
1914. Notes on some diseases of trees in our national forests. IV. Phytopathology 4: 181-188.

Fomes pinicola Fr. has been reported or collected on Pacific silver fir.

239. Heinig, Melburn, and Simmonds, F. A.
1948. Length and width of unbleached sulphate pulp fibers from certain western woods. Paper Indus. & Paper World 30: 738-741, illus.

Pacific silver fir fibers averaged longer and wider than those of Douglas-fir, western hemlock, and western redcedar.

240. Henderson, Louis F.
1936. The early flowering of plants in Lane County, Oregon, in 1934. Univ. Oreg. Monog. Stud. Bot. 1, 16 pp.

241. Henry, Joseph Kaye.
1915. Flora of southern British Columbia and Vancouver Island, with many references to Alaska and northern species. 363 pp. Toronto: W. S. Gage.

242. Hergert, H. L., and Goldschmid, Otto.
1958. Biogenesis of heartwood and bark constituents. I. A new taxifolin glucoside. Jour. Organic Chem. 23: 700-704.

Extracts were taken from wood, bark, and/or needle samples of Sitka spruce, western hemlock, western redcedar, western larch, grand fir, Pacific silver fir, Atlas cedar, and baldcypress. A trace of taxifolin-3'-glucoside was found in the needles of Pacific silver fir, but no taxifolin was present in the needles, bark, sapwood, or heartwood. Additional flavonol glucosides were also present in Pacific silver fir needles.

243. Herrin, Charles.
1892. Conifers at Dropmore. Jour. Hort. Soc. London 14: 61-66.

244. Hetherington, J. C.
1960. E. P. 538--seed dissemination and the influence of weather conditions on this process on the west coast of Vancouver Island. In Forest Research Review, year ended March, 1960. Brit. Columbia Forest Serv., pp. 21-23, illus.

Seed traps were placed in a 70-acre clearing surrounded by timber composed of western hemlock, 45 percent; Pacific silver fir, 40 percent; western redcedar, 14 percent; and Sitka spruce, 1 percent. Approximately 80,000 western hemlock, 15,000 western redcedar, and 900 Pacific silver fir seeds were collected, most of the Pacific silver fir and western redcedar seed falling within the timber.

Seedfall commenced September 16 for Pacific silver fir, September 21 for western redcedar, and September 23 for western hemlock; the peak seedfall period occurred at the end of September for Pacific silver fir, in November for western redcedar, and from November to March for western hemlock. The disintegration of Pacific silver fir cones is hastened by conditions of low humidity.

245. Hetherington, J. C.
1961. E. P. 538--seed dissemination and the influence of weather conditions on this process on the west coast of Vancouver Island. In Forest Research Review, year ended March, 1961. Brit. Columbia Forest Serv., pp. 13-15, illus.

Most Pacific silver fir seed fell less than 90 feet beyond the margins of the forest stand and its germinative capacity averaged 18 percent.

246. Heusser, C. J.
1954. Alpine fir at Taku Glacier, Alaska, with notes on its postglacial migration to the Territory. Torrey Bot. Club Bul. 81: 83-86, illus.

247. Heusser, Calvin J.
1952. Pollen profiles from southeastern Alaska. Ecol. Monog. 22: 331-352, illus.

248. ____________
1960. Late-Pleistocene environments of North Pacific North America. Amer. Geog. Soc. Spec. Pub. 35, 308 pp., illus.

Presents and discusses late-Pleistocene plant geography and the associated climatic and physiographic changes in the Pacific Coast regions from Kodiak Island, Alaska, south to Fort Bragg, California. Palynological methods and the establishment of a chronology based on radiocarbon dating and stratigraphic correleations are used. With the possible exception of the large pollen grains of subalpine fir, the true firs could not be positively distinguished from one another by palynological methods. Heusser, however, with a knowledge of their respective ranges and forest associates, was able to draw some tentative conclusions about their respective roles in forest succession. For example, grand fir is associated with Douglas-fir and Pacific silver fir is associated with mountain hemlock. So, when true fir fossil pollen grains increase and decrease with Douglas-fir pollen grains in the sediment, grand fir is probably the true fir represented in the profile.

Pollen profiles at Menzies Bay suggest that Pacific silver fir migrated into the dry eastern sector of Vancouver Island during the humid Late Postglacial. In northern British Columbia Pacific silver fir has recently increased in numbers. "True fir [probably *amabilis*] developed contemporaneously with mountain hemlock during the Late-glacial at Humptulips...[near] the Olympic Mountains.... Amabilis fir also appears to be the species that was associated with mountain hemlock during the Early Postglacial at Malahat, Menzies Bay, Harbledown Island, and as far north as Upper Hope Island in British Columbia."

Pollen profiles from Masset support the observations that true firs have not occurred on the Queen Charlotte Islands during the Postglacial.

249. Higinbotham, N., and Higinbotham, Betty Wilson.
1954. Quantitative relationships of terrestrial mosses with some coniferous forests at Mt. Rainier National Park. Butler Univ. Bot. Studies 11: 149-168.

Frequency and coverage estimates of terrestrial mosses, made in 13 forest stands representing 5 climax forest communities, indicated correlations of moss species with tree species in terms of the former's abundance. The predominant moss species in the Douglas-fir community was *Eurhynchium oreganum*; in the western hemlock-western redcedar community and the Pacific silver fir—western hemlock community, *Rhytidiopsis robusta* was the predominant moss; *Dicranum fuscesens* was the predominant moss in the Pacific silver fir—mountain hemlock community. Mosses observed beneath alpine fir community were forms generally characteristic of mineral soils.

250. Hofmann, J. V.
1917. Natural reproduction from seed stored in the forest floor. Jour. Agr. Res. 11: 1-26, illus.

251. ________
1925. Laboratory tests on effect of heat on seeds of noble and silver fir, western white pine, and Douglas fir. Jour. Agr. Res. 31: 197-199.

Seed samples of noble fir, Pacific silver fir, western white pine, and Douglas-fir were subjected for 10 hours to dry heat varying from 100° to 300° F. and moist heat varying from 100° to 240° F. Microscopic examinations of the seed and germination tests were made after the treatments. Pacific silver fir had the lowest number of seeds germinating after all temperature treatments. (However, it was not stated whether this was due to heat treatments or low-quality seeds.) There was no apparent change in the general physical appearance of Pacific silver fir seed subjected to dry heat until 140° F. when a slight drying was noticed, the endosperm was whiter and pitch began to ooze from the seed coats by 160° F., at 200° F. the seeds began to stick together, and by 300° F. the seeds had browned and were stuck to their container. There was no apparent change under moist heat until 240° F. when the seeds stuck to one another.

252. Hogan, J. B.
1950. Forest Service reports damage to Pacific silver fir. Jour. Forestry 48(6): 429.

Several species of *Pseudohylesinus* are primarily responsible for the killing of Pacific silver fir in the Mount Baker National Forest.

253. Hooker, J. D.
1864. Account of the botanical collections made by David Lyall, surgeon and naturalist to the North American Boundary Commission. Jour. Linnean Soc. London 7: 124-144.

254. Hoopes, Josiah.
1868. The book of evergreens; a practical treatise on the coniferae or cone-bearing plants. 435 pp., illus. New York: Orange Judd & Co.

255. Hopping, George.
1925. A key to the true firs of North America. Oreg. Agr. Col. Forestry Club Ann. Cruise [6]: 43-46, illus.

256. Hornibrook, Murray.
1923. Dwarf and slow-growing conifers. 195 pp., illus. New York: Charles Scribner's Sons.

257. Howard, Alexander L.
1948. A manual of the timbers of the world. Their characteristics and uses. Ed. 3, 751 pp., illus. London: MacMillan & Co. Ltd.

258. Howell, Thomas.
1903. A flora of Northwest America. v. 1, Phanerogamae. 792 pp., Portland, Oreg. (No publisher recorded.)

259. Hultén, Eric.
1941. Flora of Alaska and Yukon. I. Pteridophyta, Gymnospermae, and Monocotyledonae (Pandanales and Helobiae). Lunds Univ. Aarsskr. N.F. Avd. 2, Bd. 37, Nr. 1, pp. 1-127, illus.

Hultén reported that he has not seen any specimen of Pacific silver fir in Alaska. However, he cites its Alaskan distribution as reported by others: Pacific silver fir occurs from sea level to elevations of 1,000 feet in the Boca de Quadra and Portland Canal regions in Alaska.

260. __________
1960. Flora of the Aleutian Islands, and westernmost Alaska peninsula with notes on the flora of Commander Islands. Ed. 2 (rev.), 376 pp., illus. Weinheim/Bergstr: J. Kramer.

261. Hunnewell, Walter.
1949. The pinetum at Wellesley, Massachusetts. Univ. Wash. Arboretum Bul. 12(4): 22, 23, 33.

262. Hunter, Lillian M.
1927. Comparative study of spermogonia of rusts of *Abies*. Bot. Gaz. 83: 1-23.

263. Hutchison, A. H.
1924. Embryogeny of *Abies*. Bot. Gaz. 77: 280-289.

264. Hylander, Clarence J.
1939. The world of plant life. 722 pp., illus. New York: Macmillan Co.

265. Isaac, Leo A.
1956. Where do we stand with Douglas-fir natural regeneration research? Soc. Amer. Foresters Proc. 1955: 70-72.

266. __________
1956. Place of partial cutting in old-growth stands of the Douglas-fir region.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 16, 48 pp., illus.

Pacific silver fir, as a member of the understory species component, usually showed accelerated growth after the partial cutting of old-growth Douglas-firs.

267. __________
1960. Leo A. Isaac on silviculture. 32 pp., illus. Corvallis: Oregon State College Press.

268. Jay, B. Alwyn.
1952. Conifers in Britain. An illustrated guide to identification. 47 pp., illus. London: Adam & Charles Black.

Provides a key for each genus and good photographs of the foliage and buds of the species included. Pacific silver fir "succeeds best in highlands of Wales and Scotland."

269. Jeffrey, Edward C.
1904. The comparative anatomy and phylogeny of the coniferales. Pt. 2.--The Abietineae. Mem. Boston Nat. Hist. 6: 1-37, illus.

270. Jenkins, J. H.
1926. The kiln-drying of British Columbia softwoods. Canada Dept. Int. Forest Serv. Cir. 18, 13 pp.

271. __________ and Guernsey, F. W.
1954. The kiln-drying of British Columbia lumber. Canada Dept. North. Aff. & Natl. Resources Forestry Branch Bul. 111, 80 pp., illus.

272. Johnson, F. A.
1955. Volume tables for Pacific Northwest trees. U.S. Dept. Agr. Handb. 92, 122 tables.

A compilation of mostly regional volume tables giving volumes of the tree species up to various d.i.b.'s in both cubic-foot and board-foot units of measure. Log rules used were International 1/8- and 1/4-inch rule, and Scribner rule. Accuracy, methods, source, and other pertinent information head each table. Board-foot variables are d.b.h. and either total height or number of 16- or 32-foot logs.

Pacific silver fir is represented by eight tables.

273. Johnson, Norman E.
1959. *Pineus* infestation on true firs in western Washington. Jour. Econ. Ent. 52: 828-829, illus.

A chermid of the genus *Pineus* is reported feeding on the bole and branches of Pacific silver and grand firs. The insect apparently does not cause the gouting and serious damage of the balsam woolly aphid *(Chermes piceae)* but is very similar to the latter in general appearance.

274. __________ and Heikkenen, H. J.
1958. A method for field studies of the balsam woolly aphid. Jour. Econ. Ent. 51: 540-542, illus.

275. __________ Mitchell, Russell G., and Wright, Kenneth H.
1963. Mortality and damage to Pacific silver fir by the balsam woolly aphid in southwestern Washington. Jour. Forestry 61: 854-860, illus.

276. __________ and Wright, Kenneth H.
1957. The balsam woolly aphid problem in Oregon and Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 18, 34 pp., illus.

A complete presentation of the balsam woolly aphid problem in the Northwest, including a discussion of the insect *(Adelges piceae* Ratz.) and its habits and a report of control actions being undertaken and actions which should be undertaken in the future.

The most serious epidemic was on Pacific silver fir in the Cascade Range of southern Washington, particularly in large sawtimber stands near Mount St. Helens. Other infestations had been noted on silver fir as far north as Mount Rainier, in the

Cascade Range of northern Oregon from Mount Hood southward to Crater Lake National Park, and in a nearly pure stand of large sawtimber in the Oregon Coast Ranges in Polk and Lincoln Counties. The large quantities of dead and dying timber resulting from these attacks have had a very disturbing effect on forest management plans in the affected areas, necessitating large salvage programs by public and private owners; these programs will probably have a disturbing effect on lumber manufacture and marketing programs. Neither sawmills nor pulpmills are geared to handle the large volume of true fir salvage timber anticipated.

Details of the insect's history in North America, description, seasonal history, method of spread, and effect on the host are included in the paper. Detailed biological studies of balsam woolly aphid have been made only in Pacific silver fir stands near Mount St. Helens. The life cycle in the Northwest differs from those in the Northeast and Europe primarily in an overlapping of summer and winter generations and a longer period of seasonal activity. Wind has been the principal means of dispersion in the Pacific Northwest, although the possibility of spread through the distribution of infected nursery stock should be checked by frequent nursery inspections. Insect attack on twigs causes contorted swellings (gout), inhibiting the growth of new foliage to the extent that death may result. Death may result even more quickly from infestations on the main stems of trees. Pacific silver fir usually dies from the top down. The aphid has shown a preference for mature or overmature silver fir, the only young trees affected being in the understory of infested stands or immediately adjacent to them. No significant infestations have been found on silver fir regeneration in clear cuts.

Several control methods--natural, chemical, and silvicultural--are suggested. Silvicultural means particularly relevant to silver fir include: replacement of Pacific silver fir by noble fir at higher elevations and Douglas-fir and hemlock at low elevations; tests of undamaged silver fir trees found in heavily infected stands to determine if they are chemically or physically resistant and, if so, why; management of Pacific silver fir on a short rotation based on the observation that only mature and overmature stands have been significantly attacked and the largest trees appear to be the hardest hit; and removal of all mature silver fir from mixed stands as far back from the timber cutting edge as possible.

277. Jones, George Neville.
1936. A botanical survey of the Olympic Peninsula, Washington. Univ. Wash. Pub. Biol., v. 5, 286 pp., illus.

278. ________
1938. The flowering plants and ferns of Mount Rainier. Univ. Wash. Pub. Biol., v. 7, 192 pp., illus.

279. Jones, W. S.
1924. Timbers, their structure and identification. 148 pp., illus. Oxford: Clarendon Press.

Ray tracheids have been observed in Pacific silver fir after injury.

280. Keen, F. P.
1952. Insect enemies of western forests. U.S. Dept. Agr. Misc. Pub. 273 (rev.), 280 pp., illus.

Contains listings and descriptions of insect pests that attack Pacific silver fir. Type of damage and control measures are also discussed.

281. Keen, F. P.
1958. Cone and seed insects of western forest trees. U.S. Dept. Agr. Tech. Bul. 1169, 168 pp., illus.

Lists and discusses insect species reared from cone collections of western forest trees. Descriptions of the insects, their seasonal history, distribution, hosts, parasites, and predators and control measures are presented. No cone collections were made from Pacific silver fir, but Keen believes that the same insect species damages all species of true fir. These insects are mainly in the cone maggots, cone moths, and seed chalcid groups.

282. Kelsey, Harlan P., and Dayton, William A.
1942. Standardized plant names. Ed. 2, 675 pp. Harrisburg: J. Horace McFarland Co.

283. Ker, J. W., and Smith, J. H. G.
1957. Sampling for height-diameter relationships. Jour. Forestry 55: 205-207.

284. King, James P.
1961. Growth and mortality in the Wind River Natural Area. Jour. Forestry 59: 768-770, illus.

Growth and mortality observations in a 350-year-old stand of Douglas-fir show that the still considerable annual stand growth is being offset by mortality. In some places in the stand, decadent Douglas-fir is being replaced by western hemlock and Pacific silver fir; in other parts of the stand, the latter species are just beginning to form part of the overstory.

The annual growth and mortality data show the gross growth for Douglas-fir, western hemlock, and Pacific silver fir to be 179, 397, and 72 board feet (Scribner rule), respectively; the mortality, 350, 149, and 31 board feet. This leaves a net growth for the three species of -171, 248, and 41 board feet, respectively.

285. Kinghorn, J. M.
1954. The influence of stand composition on the mortality of various conifers, caused by defoliation by the western hemlock looper on Vancouver Island, British Columbia. Forestry Chron. 30: 380-400, illus.

Forest stands of Douglas-fir, Pacific silver fir, western hemlock, and Sitka spruce were subjected to 4 years of defoliation by the hemlock looper. In general, tree mortality increased directly with degree of defoliation. Multiple regression equations were presented to show the relation of basal area mortality to stand composition and percent defoliation; they showed that the mortality of larger trees (excluding Douglas-fir) was higher in all defoliation classes.

286. Klaehn, F. U., and Winieski, J. A.
1962. Interspecific hybridization in the genus Abies. Silvae Genetica 11: 130-142, illus.

Reports natural crossing of subalpine fir and Pacific silver fir and the artificial crossing of white fir and Pacific silver fir.

287. Klein, William H., and Wright, Kenneth H.
1960. Final report, accomplishments of the Silver Fir Beetles Committee, 1954 to 1959. U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. unpublished office report, 17 pp.

An outbreak of silver fir beetles in northern Washington precipitated the appointment of the Silver Fir Beetles Committee by the Northwest Forest Pest Action Council in 1953. This report summarizes developments and the work done by the committee until it was disbanded in 1959. Cooperative surveys showed 528 million board feet of Pacific silver fir sawtimber were killed up to 1954. Trend data obtained from cooperative plots in the Mount Baker area of Washington indicated a sharp decline in Pacific silver fir mortality after 1954. Similar data from the Olympic Mountains of Washington showed neglibible mortality of silver fir over the entire period of the study. In 1959, vigor of silver fir on both areas was good.

288. Knauss, A. C.
1955. Seasoning defects of western softwoods. Seventh Ann. Meeting West. Dry Kiln Clubs Proc., pp. 10-18.

289. Krajina, V. J.
1961. 1960 progress report on N.R.C. Grant No. T-92 entitled ecology of the forests of the Pacific Northwest. Univ. Brit. Columbia Dept. Biol. Bot., 62 pp., illus.

See abstract of next reference.

290. ___________
1962. 1961 progress report on N.R.C. Grant No. T-92 entitled ecology of the forests of the Pacific Northwest. Univ. Brit. Columbia Dept. Biol. Bot., 37 pp., illus.

Reviews some research presently in progress in British Columbia. Pacific silver fir is included in the studies of: nutrition of grand fir and amabilis fir in the greenhouse; ecological study of forest types and soils in the Coastal Western Hemlock Zone; plant communities and ecotypes of plant communities in the ecosystem classification of the Coastal Subalpine Zone in British Columbia; and ecological studies in the subalpine-alpine ecotone of Garibaldi Park.

291. Krajina, Vladimir J.
1959. Bioclimatic zones in British Columbia. Univ. Brit. Columbia Bot. Ser. 1, 47 pp., illus.

The vegetation climate and zonal soil groups of bioclimatic zones in British Columbia. Pacific silver fir is characteristic of the climatic and edaphic climaxes of the "Coastal Western Hemlock Zone" and the "Subalpine Mountain Hemlock Zone."

292. Krüssmann, Gerd.
1960. Die Nadelgehölze. Ed. 2 (rev.), 335 pp., illus. Berlin and Hamburg: Paul Parey.

293. Krueger, Kenneth W.
1960. Behavior of ground vegetation under a partially cut stand of Douglas-fir.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 198, 3 pp.

294. Lamb, Frank H.
1938. Sagas of the evergreens; the story and the economic, social and cultural contribution of the evergreen trees and forests of the world. 364 pp., illus. New York: W. W. Norton & Co., Inc.

295. Lamb, William H.
1914. A conspectus of North American firs (exclusive of Mexico). Soc. Amer. Foresters Proc. 9: 528-538, illus.

A taxonomic description of American true firs which places considerable emphasis on the form of the cone bract.

296. Lang, Walter.
1962. Growth studies of Pacific silver fir, *Abies amabilis* (Dougl.) Forb. M.F. thesis on file Univ. Wash. 101 pp., illus.

A study of growth and yield of Pacific silver fir in the Mount Baker area. Growth of Pacific silver fir in this area was found to approximate yields of site I European silver fir stands in Europe.

297. Langille, H. D., Plummer, Fred G., Dodwell, Arthur, and others.
1903. Forest conditions in the Cascade Range Forest Reserve, Oregon. U.S. Geol. Survey Prof. Paper 9, 298 pp., illus.

298. Lanner, Ronald M.
1962. Controlling the moisture content of conifer pollen. Silvae Genetica 11: 114-117, illus.

Pollen of nine species of pine, true fir (including Pacific silver fir), Douglas-fir, and true cedar was placed in a series of constant humidity chambers until it reached equilibrium moisture content. The time to reach equilibrium depended upon the differences between the initial moisture content and the equilibrium moisture content of the atmosphere. Species of pine and true fir reached similar equilibria.

299. Laslett, Thomas.
1894. Timber and timber trees. Ed. 2, 442 pp., illus. London: MacMillan and Co.

300. Lawrence, Donald B.
1939. Some features of the vegetation of the Columbia River Gorge with special reference to asymmetry in forest trees. Ecol. Monog. 9: 218-257, illus.

301. Leiberg, John B.
1900. Cascade Range Forest Reserve, Oregon, from Township 28 south to Township 37 south, inclusive; together with the Ashland Forest Reserve and adjacent forest regions from Township 28 south to Township 41 south, inclusive, and from Range 2 west to Range 14 east, Willamette meridian, inclusive. U.S. Geol. Survey 21st Ann. Rpt. 1899-1900, Pt. 5, Forest Reserves: 209-498, illus.

302. Lewis, R. G.
[n.d.] Commercial forest trees of Canada. Canada Dept. of Int. Forestry Branch Cir. 14, 8 pp.

303. Little, Elbert L., Jr.
1944. Notes on nomenclature in Pinaceae. Amer. Jour. Bot. 31: 587-596.

The names *Abies grandis* and *A. amabilis* perhaps were not used for the plants with which they had been associated originally. The incomplete evidence was summarized, including new evidence that the name *Pinus grandis* Dougl. was published in 1832.

304. ________
1953. Check list of native and naturalized trees of the United States (including Alaska). U.S. Dept. Agr. Handb. 41, 472 pp.

The accepted scientific name of Pacific silver fir is *Abies amabilis* (Dougl.) Forbes. Some common names are: Cascades fir, amabilis fir, lovely fir, red fir, and white fir.

305. ________
1949. Important forest trees of the United States. U.S. Dept. Agr. Yearbook 1949: 763-814, illus. (Reprinted in 1950 as U.S. Dept. Agr. Yearbook Separate 2156.)

306. Lodewick, J. Elton, and Harrar, Ellwood S.
1937. What wood is that? Timberman 38(8): 33, 34, 36, 38, 40, illus.

307. Lyons, C. P.
1952. Trees, shrubs and flowers to know in British Columbia. 168 pp., illus. Toronto, Vancouver: J. M. Dent & Sons (Canada) Ltd.

308. ________
1956. Trees, shrubs and flowers to know in Washington. 211 pp., illus. Toronto, Vancouver: J. M. Dent & Sons (Canada) Ltd.

309. McAvoy, Blanche.
1931. Ecological survey of the Bella Coola region. Bot. Gaz. 92: 141-171, illus.

Pacific silver fir occurs in nearly pure stands on Canoe Crossing Mountain from 1,098 meters to 1,310 meters in altitude.

310. MacBean, A. P.
1941. A study of the factors affecting the reproduction of western hemlock and its associates in the Quatsino region, Vancouver Island. Brit. Columbia Dept. Lands Forest Branch, 36 pp., illus.

Contains tables comparing seedling growth of western hemlock, Pacific silver fir, Sitka spruce, and western redcedar.

311. McBride, C. F.
1957. Sawmill residue in the Prince George Area of British Columbia. Canada Dept. North. Aff. & Natl. Resources Forestry Branch Forest Prod. Lab. Div. V-1013, 28 pp., illus.

312. MacDonald, J. Alan B.
1950. Conifers on the west coast of Scotland. Univ. Wash. Arboretum Bul. 13(2): 14, 15, 30.

A general discussion of the success of exotic coniferous plantings in Scotland. Pacific silver fir is among the western American species making promising growth on moorlands.

313. Macdonald, James, Wood, R. F., Edwards, M. V., and Aldhous, J. R., eds.
1957. Exotic forest trees in Great Britain. Gt. Brit. Forestry Comn. Bul. 30, 167 pp., illus.

Pacific silver fir was first introduced by Douglas in 1830. Few survived, however, so it was reintroduced in 1882. The species was never widely planted and is considered by some as a failure in cultivation. One tree has a height of 99 feet and is presumed to be the largest in the country.

An extremely successful plantation exists at Crarae, Argyllshire. In 23 years the trees have grown 38 feet in height and have an average d.b.h. of 15 inches. The present volume is 2,000 Hoppus feet per acre--396 Hoppus feet have been removed in thinnings.

The most promising environments are the better mountain soils in western Britain. Because it is highly shade tolerant, Pacific silver fir is considered for underplanting or the conversion of poor broadleaved shrub to high forest.

314. McElhanney, T. A., and Perry, R. S.
1927. Some commercial softwoods of British Columbia; their mechanical and physical properties. Canada Dept. Int. Forest Serv. Bul. 78, 45 pp., illus.

315. McGugan, B. M.
1958. Forest lepidoptera of Canada recorded by the Forest Insect Survey, v. 1 - Papilionidae to Arctiidae. Canada Dept. Agr. Forest Biol. Div. Pub. 1034, 76 pp., illus.

Halisidota argentata Pack., an Artiidae defoliator was recorded feeding on Pacific silver fir.

316. Mackay, Margaret Rae.
1962. Larvae of the North American Tortricinae (Lepidoptera: Tortricidae). Canad. Ent. Sup. 28, 182 pp., illus.

Pacific silver fir is one of the hosts of *Choristoneura fumiferana* Clemens and *Choristoneura ex Pseudotsuga menziesii*.

317. MacLean, Colin D., and Hightree, Paul E.
1959. Forest statistics for Skagit and Whatcom Counties, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 133, 47 pp., illus.

In 1957, there was 5,289 million board feet (Scribner rule, trees 11.0 inches d.b.h. and larger) of Pacific silver fir live sawtimber in Skagit County. This amounted to 35 percent of the total sawtimber volume. Pacific silver fir growing-stock volume amounted to 1,178 million cubic feet (sound trees 5.0 inches d.b.h. and larger to a 4-inch top inside bark), which is 34 percent of the total growing-stock volume.

In Whatcom County, Pacific silver fir comprised 29 percent of the live sawtimber volume (3,214 million board feet, Scribner) and 26 percent of the growing-stock volume (703 million cubic feet).

318. McMahon, R. O.
1961. The economic significance of mortality in old-growth Douglas-fir management.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 37, 21 pp., illus.

319. McMinn. Howard E., and Maino, Evelyn.
1956. An illustrated manual of Pacific Coast trees. Ed. 2, 409 pp., illus. Berkeley: University California Press.

320. M'Nab, William Ramsay.
1877. A revision of the species of *Abies*. Royal Irish Acad. Proc., ser. 2, 2: 673-704, illus.

321. Makins, F. K.
1936. The identification of trees and shrubs. 326 pp., illus. London: Dent & Sons Ltd.

322. Marckworth, Gordon D.
1951. Fundamental research in the growth of trees and stands at the College of Forestry. Univ. Wash. Forest Club Quart. 24(1): 3-7.

323. Markwardt, L. J.
1930. Comparative strength properties of woods grown in the United States. U.S. Dept. Agr. Tech. Bul. 158, 39 pp., illus.

324. __________
1941. Aircraft woods: their properties, selection and characteristics. U.S. Forest Serv. Forest Prod. Lab. Rpt. 1079, 51 pp., illus.

325. __________ and Wilson, T. R. C.
1935. Strength and related properties of woods grown in the United States. U.S. Dept. Agr. Tech. Bul. 479, 99 pp., illus.

Includes tabulated data on strength and other properties of Pacific silver fir wood. The wood tested was from six trees grown in Snohomish County, Wash. Information is provided on rings per inch, summerwood percent, moisture content, specific gravity, weight, shrinkage, maximum tensile strength, and results of static bending, impact bending, compression, hardness, shear, and cleavage tests.

326. Massee, G.
1905. *Abies amabilis*, diseased. Jour. Roy. Hort. Soc. London 31: LXXXIV.

Pacific silver fir was badly affected by *Chermes abietis*.

327. M[asters], M. T.
1880. *Abies amabilis*. Gard. Chron., n.s., 14: 720-721, 725, illus.

A report of the rediscovery of *Abies amabilis* at the type locality in 1880 by G. Engelmann, C. S. Sargent, and C. C. Parry.

328. Masters, M. T.
1900. *Abies amabilis* attacked by Chermes. Jour. Roy. Hort. Soc. London 25: XXVIII.

"Dr. Masters showed specimens of this tree, also called *A. lowiana,* with gouty branches. The bark was badly infested by an aphis much resembling that which attacks beeches...."

329. Masters, Maxwell T.
1886. Contributions to the history of certain species of conifers. Jour. Linn. Soc. [London] Bot. 22: 169-212, illus.

330. ________
1892. List of conifers and taxads in cultivation in the open air in Great Britain and Ireland. Jour. Roy. Hort. Soc. London 14: 179-256.

Lists the accepted scientific names and synonyms for the various species and the botanists that named and described the species.

331. ________
1892. Some features of interest in the order of conifers. Jour. Roy. Hort. Soc. London 14: 1-18.

A general presentation superficially covering the antiquity, genealogy, stages of growth, physiology, appearance, utility nomenclature, economic value, and introduced species of conifers in England.

Mentions that it is difficult to obtain a leader in Pacific silver fir without insect or fungal injury. Masters believes this is because the lateral buds, circling the terminal bud, commence growth in the spring before the terminal bud, thereby appropriating much of the nourishment. A leader is easily secured by suppression of the lateral buds.

332. ________
1901. Hybrid conifers. Jour. Roy. Hort. Soc. London 26: 97-110, illus.

The compilation of reported hybrids included *Abies lasiocarpa* X *A. amabilis* Sargent.

333. Matson, E. E.
1957. White fir lumber recovery at a western Washington sawmill.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 141, 8 pp., illus.

Presents in tabular and graphical form volume and lumber grade recovery data from 166 Pacific silver fir and grand fir logs. The lumber industry groups these species together and sells them as white fir.

334. Meagher, G. S.
1946. Forest statistics for Clackamas County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 97, 20 pp., illus.

335. Melville, R.
1957. *Abies amabilis;* coniferae. Curtis's Bot. Mag., n.s., 171: tab. 306. 4 pp., illus.

336. Melville, R.
1959. Notes on gymnosperm nomenclature. Kew Bul. 3 [1958]: 531-535.

Discusses the early confusion between the identities of grand fir and Pacific silver fir which apparently arose from the earliest description of David Douglas' specimens being made from a mixture, possibly because the two species did not appear sufficiently distinct enough to be separated. This mistake caused some confusion among botanists until Forbes correctly identified both species and Pacific silver fir was subsequently rediscovered in 1880 by Engelmann, Parry, and Sargent.

337. Miller, Vera Mentzer, and Bonar, Lee.
1941. A study of the Perisporiaceae, Capnodiaceae, and some other sooty molds from California. Univ. Calif. Pub. Bot. 19: 405-417.

Phaeosaccardinula dematia sp. nov. was found on Pacific silver fir near Adelaide Lake, Mount Rainier National Park, Washington, in September 1935 by H. E. Bailey.

338. Milliron, H. E.
1949. Taxonomic and biological investigations in the genus *Megastigmus*, with particular reference to the taxonomy of the Nearctic species (Hymenoptera: Chalcidoidea; Callimomidae). Amer. Midland Nat. 41: 257-420, illus.

A very thorough presentation of all information known up to 1949 on the taxonomy and biology of the genus *Megastigmus*. Pacific silver fir is a host for *Megastigmus lasiocarpae* Cy. and *Megastigmus pinus* Parf.

339. Mitchell, A. F.
1963. The Dropmore Pinetum. Gt. Brit. Forestry Comn. Forest Rec. 48, 39 pp., illus.

This publication contains a list of species and best trees in the Pinetum; Pacific silver fir is included.

340. Mitchell, Russel G.
1962. Balsam woolly aphid predators native to Oregon and Washington. Oreg. Agr. Expt. Sta. Tech. Bul. 62, 63 pp., illus.

341. __________ Johnson, Norman E., and Rudinsky, Julius A.
1961. Seasonal history of the balsam woolly aphid in the Pacific Northwest. Canad. Ent. 93: 794-798, illus.

342. Molnar, A. C.
1954. Forest disease survey. British Columbia. Canada Dept. Agr. Forest Insect & Disease Survey Ann. Rpt. 1953: 150-158.

343. __________
1955. Forest disease survey. British Columbia. Canada Dept. Agr. Forest Insect & Disease Survey Ann. Rpt. 1954: 128-135.

Lachnella agassizii (Berk. and Curt.) Seaver was recorded for the first time on Pacific silver fir at Kitimat, British Columbia.

344. Molnar, A. C.

1956. Forest disease survey. British Columbia. Canada Dept. Agr. Forest Insect & Disease Survey Ann. Rpt. 1955: 102-106.

A sooty mold fungus, *Limacinia alaskensis* Sacc. and Scalia, was found causing damage to Pacific silver fir foliage at Kitimat, Cowichan Lake, and Forbidden Pateau, V. I.

345. ________

1959. Forest disease survey. British Columbia. Canada Dept. Agr. Forest Insect & Disease Survey Ann. Rpt. 1958: 97-103.

Flammula alnicola (Fr.) Quél. and *Merulius himantioides* Fr. were cultivated for the first time on Pacific silver fir at Duncan, V. I. Pacific silver fir was inoculated with *Uredinopsis pteridis* Diet. & Holw. at Cordova Bay, V. I.

346. Moravets, F. L.

1943. Forest statistics for Lane County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 92, 23 pp., illus.

347. ________

1943. Part I. The forest resource. In Forest Resources of Oregon. Oreg. State Bd. Forestry and Oreg. State Col. School Forestry, pp. 7-28, illus.

348. ________

1947. Forest statistics for Multnomah County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 98, 15 pp., illus

349. ________

1952. Forest statistics for Cowlitz County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 105, 24 pp., illus.

In 1949, the net volume of live Pacific silver fir sawtimber on commercial forest land in Cowlitz County was estimated to be 1,672 million board feet (Scribner). Growing stock was estimated as 339 million cubic feet.

350. ________

1953. Forest statistics for Grays Harbor County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 111, 24 pp., illus.

The net volume of live Pacific silver fir timber in Grays Harbor County was 2,721 million board feet (Scribner) in 1951. Growing-stock volume was 509 million cubic feet.

351. ________

1953. Forest statistics for Lewis County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 112, 24 pp., illus.

The net volume of live Pacific silver fir sawtimber in Lewis County was 2,231 million board feet (Scribner) in 1952. Growing-stock volume was 517 million cubic feet.

352. ________ 1953. Forest statistics for Mason County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 110, 24 pp., illus.

In 1951, the net volume of Pacific silver fir sawtimber on commercial forest lands in Mason County was 194 million board feet (Scribner). Growing stock was 47 million cubic feet.

353. ________ 1953. Forest statistics for Skamania County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 107, 23 pp., illus.

The net volume of Pacific silver fir live sawtimber in Skamania County in 1950 amounted to 3,580 million board feet (Scribner). Growing stock was approximately 867 million cubic feet.

354. ________ 1954. Forest statistics for Clatsop County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 113, 24 pp., illus.

The net volume of Pacific silver fir live sawtimber on commercial forest land in Clatsop County was 92 million board feet (Scribner) in 1952. Growing-stock volume was 27 million cubic feet.

355. ________ 1954. Forest statistics for Deschutes County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 116, 24 pp., illus.

In 1953, the net volume of Pacific silver fir sawtimber on commercial forest land in Deschutes County was computed as 7 million board feet (Scribner). Growing-stock volume was 2 million cubic feet.

356. ________ 1954. Forest statistics for Jefferson County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 115, 23 pp., illus.

The net volume of Pacific silver fir live sawtimber on Commercial forest lands in Jefferson County was estimated as 51 million board feet (Scribner) in 1953. Growing-stock volume was estimated as 18 million cubic feet.

357. ________ 1954. Forest statistics for Kittitas County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 117, 24 pp., illus.

In 1953, the net volume of Pacific silver fir sawtimber on commercial forest lands in Kittitas County was estimated as 1,341 million board feet (Scribner). Growing stock was 308 million cubic feet.

358. Morrill, George E.
1946. Forest statistics for Marion County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 96, 21 pp., illus.

359. Morton, B. R.
1921. Native trees of Canada. Canada Dept. Int. Forestry Branch Bul. 61, 233 pp., illus.

360. Mosher, Milton M., and Lunnum, Knut.
1959. Trees of Washington. Wash. State Col. Inst. Agr. Sci. Ext. Bul. 440 (reprint), 40 pp., illus.

361. Mueller, Dombois Deiter.
1959. The Douglas-fir forest associations on Vancouver Island in their initial stages of secondary succession. Unpublished Ph. D. thesis on file Univ. Brit. Columbia, 570 pp., illus.

Western hemlock and Pacific silver fir are the prominent tree species in submountainous forest associations which occur in the upper and western fringe zones of the study areas.

362. Muenscher, W. C.
1941. The flora of Whatcom County, State of Washington. 134 pp., illus. Ithaca, N.Y.

363. Mulholland, F. D.
1937. The forest resources of British Columbia. Brit. Columbia Forest Serv., 153 pp., illus.

Grand fir, Pacific silver fir, and alpine fir are grouped under silver fir. They include 17,580 million board feet of timber in coastal forests (11 percent of the total) and 13,904 million board feet of timber in the interior stands (14 percent of the total). On good sites, Pacific silver fir grows from 3 to 5 feet in diameter and 150 to 200 feet in height.

364. Mulligan, B. O., and Michaud, L. J.
1950. Raising conifers from seeds at Arboretum. Univ. Wash. Arboretum Bul. 13(2): 35-36.

A listing by species of germination information from coniferous seeds sown at the University of Washington Arboretum.

365. Munger, Thornton T.
1927. Timber growing and logging practice in the Douglas fir region. U.S. Dept. Agr. Dept. Bul. 1493, 42 pp., illus.

366. ________
1940. The cycle from Douglas fir to hemlock. Ecology 21: 451-459, illus.

367. Munns, E. N.
1938. The distribution of important forest trees of the United States. U.S. Dept. Agr. Misc. Pub. 287, 176 pp., illus.

Contains maps of the botanical ranges of the important tree species, including Pacific silver fir.

368. Munroe, Eugene.
1959. Canadian species of *Dioryctria* Zeller (Lepidoptera: Pyralidae) Canad. Ent. 91: 65-72, illus.

Pacific silver fir is one of the hosts of *Dioryctria reniculella* Grote.

369. Newberry, [J. S.]
1884. On the forest trees of the country bordering the line of the Northern Pacific Railroad. Torrey Bot. Club Bul. 11(2): 21-24.

370. Newlin, J. A., and Wilson, T. R. C.
1919. The relation of the shrinkage and strength properties of wood to its specific gravity. U.S. Dept. Agr. Bul. 676, 35 pp., illus.

371. __________ and Wilson, Thomas R. C.
1917. Mechanical properties of woods grown in the United States. U.S. Dept. Agr. Bul. 556, 47 pp., illus.

372. Northcott, P. L., Colbeck, H. G. M., Hancock, W. V., and Shen, K. C.
1959. Undercure... casehardening in plywood. Forest Prod. Jour. 9: 442-451, illus.

373. Northwest Forest Tree Seed Committee.
1959. Rules for service testing forest tree seed of the Pacific Northwest.* Oreg. Agr. Expt. Sta. Misc. Paper 83, 27 pp.

Five ounces is the minimum weight of Pacific silver fir seed needed for standard tests (purity, germination, 1,000 seed count, and cutting tests); 6 ounces is the minimum for hydrogen peroxide and staining tests. At least 100 grams of Pacific silver fir seed are needed in working samples for purity analysis. There are three pretreatment methods for germination tests of Pacific silver fir seed: no pretreatment, 4 weeks' stratification at 5° C., wash 16 hours or soak 30 hours, then 1 week's stratification at 5° C. The duration of the germination tests is approximately 21 days at temperatures (with light) of 20° to 30° C.

The minimum recommended standards for Pacific silver fir seed processing are: seeds should be 50 percent filled in the cutting test, be 55 percent pure by weight, be 20 percent viable in the peroxide test, and have a moisture content of 9 to 12 percent.

374. Orr, P. W.
1963. Important insect outbreaks in Oregon and Washington in 1963.* U.S. Forest Serv. Region 6, 11 pp., illus.

Epidemic outbreaks of silver fir beetles (*Pseudohylesinus* spp.) occurred in Pacific silver fir on extensive areas of the Mount Baker and Snoqualmie National Forests with lighter damage on the Gifford Pinchot National Forest and in Mount

Rainier National Park. Many of the infested trees are also severely infected with *Armillaria mellea* root rot.

375. Ouden, P. den.
1949. Coniferen, ephedra en ginkgo. 444 pp., illus. Wageningen: H. Veeman & Zonen.

376. Pady, S. M.
1941. Further notes on the witches' brooms and the substomatal pycnia of *Melampsorella*. Kansas Acad. Sci. Trans. 44: 190-201, illus.

Contains a photograph of a cross section of subcuticular pycnia of *Melampsorella* on Pacific silver fir.

377. ________
1942. Distribution patterns in Melampsorella in the national forests and parks of the western states. Mycologia 34: 606-627, illus.

378. Paul, Benson H.
1959. The effect of environmental factors on wood quality.* U.S. Forest Serv. Forest Prod. Lab. Rpt. 2170, 48 pp.

Pacific silver fir wood has an average specific gravity of 0.37, with a variation from 0.35 for wood with 6 to 15 rings per inch to 0.41 for wood with 21 rings or more per inch. Ring widths of less than five rings per inch were not encountered among samples of Pacific silver fir, probably due to close initial stocking of young trees in natural stands. Wood samples from a high-rainfall area in the Olympic National Forest (Washington) averaged 0.38 in specific gravity, those from a lower rainfall and higher elevation area--the Gifford Pinchot and Snoqualmie National Forests (Washington)--averaged 0.35. Specific gravity varied considerably both among and within trees on all three sites. In samples from the Olympic and Gifford Pinchot Forests, younger trees averaging about 15 rings per inch were found to contain wood of much lower average specific gravity than trees about 100 years older. The heaviest wood was found in an intermediate radial position between the pith and the bark.

For production of a more uniform wood quality, close initial stocking followed by thinnings to maintain an even growth rate is recommended. True firs are often subject to heavy snowloads and consequent bending when young. Compression wood is formed on the underside of bent trees, and trees which are unable to straighten themselves form this wood indefinitely. Removal of bent and leaning trees is therefore an important phase of thinning and stand improvement work.

379. ________
1961. Properties and uses of some minor western softwoods. Hitchcock's Wood Working Digest 63(10): 26-27.

380. ________
1963. The application of silviculture in controlling the specific gravity of wood. U.S. Dept. Agr. Tech. Bul. 1288, 97 pp., illus.

See reference 378 in this bibliography.

381. Pardé, Léon Gabriel Charles.
1955. Les coniferes: ouvrage honoré d'une souscription de la Direction Générale des Eaux et Forêts. 294 pp., illus. Paris: La Maison Rustique.

382. Peattie, Donald Culross.
1953. A natural history of western trees. 751 pp., illus. Boston: Houghton Mifflin Co.

383. Peavy, George W.
1922. Oregon's commercial forests; their importance to the State. Oreg. State Bd. Forestry Bul. 2, 80 pp., illus.

384. Pechanec, Anna Alice.
1961. Some aspects of the ecology of the bryophytes in the Three Sisters Primitive Area. Unpublished Ph. D. thesis on file Oreg. State Univ., 187 pp., illus.

A survey of combinations of tree and bryophyte species indicated some correlations between the two plant groups. Forest stands were tentatively assembled in 10 groups on the basis of these correlations.

Pacific silver fir was one of the dominant (high basal area) tree species in the following groups: (group e) *Picea engelmanni* ± *Abies amabilis* and other tree species with *Brachythecium hylotapetum -B. curtum forma;* (group g) *Tsuga mertensiana* and *Abies amabilis* with *Dicranum fuscescens.*

Pacific silver fir was present but was not one of the dominant tree species in the following groups: (group f) *Abies* sp. with *Bryum sandbergii;* (group h) *Pinus contorta* and *Tsuga mertensiana* with *Polytrichum piliferum* and *P. juniperinum.*

385. Peck, Morton Eaton.
1961. A manual of the higher plants of Oregon. Ed. 2, 936 pp., illus. Portland, Oreg.: Binfords & Mort.

386. Peck, Oswald.
1963. A catalogue of the Nearctic Chalcidoidea (Insecta: Hymenoptera). Canad. Ent. Sup. 30, 1092 pp.

Megastigmus hoffmeyeri, M. lasiocarpae, M. pinus pinus, M. rafni, M. spermotrophus var. *spermotrophus,* and *M. tsugae* var. *tsugae* reported on Pacific silver fir seed.

387. Penhallow, D. P.
1896. The generic characters of the North American Taxaceae and Coniferae. Proc. and Trans. Roy. Soc. Canada, ser. 2, v. 2, sect. 5, pp. 33-57, illus.

388. Penhallow, David Pearce.
1904. The anatomy of North American coniferales together with certain exotic species from Japan and Australasia. Amer. Nat. 38: 243-273, 331-359, 523-554, 691-723, illus.

389. ________
1907. A manual of the North American gymnosperms. 374 pp., illus. Boston: Ginn & Co.

Lists, describes, and illustrates various anatomical features of certain coniferous woods. Discusses their relationships in the development of the conifers and general phylogeny of the higher gymnosperms. A key differentiates the anatomical characteristics of 92 North American species, 21 Japanese species, and 4 Australian species. Quantitative values for various strength properties are also presented.

Pacific silver fir--Transverse section: "Resin cells few and widely scattering on the outer face of the summer wood...distinguished by (1) the sieve-plate structure of the terminal wall and (2) their often advanced position. Medullary rays rather prominent, not resinous, 1 cell wide...." Radial section: "Rays non-resinous, wholly devoid of tracheids. Ray cells chiefly straight except in the summer wood...upper and lower walls thick, unequal, and coarsely but very unequally pitted...the lateral walls with small, round, or oval pits...1-2, rarely 3, or in the marginal cells sometimes 5...." Tangential section: "Rays medium to high, the cells uniform, chiefly oval, more rarely round or narrowly oval, sometimes in pairs."

390. Pernot, J. F.
1916. Forests of Crater Lake National Park. U.S. Dept. Int., 39 pp., illus.

Pernot reported that the Crater Lake region is the extreme southern limit of the botanical range of Pacific silver fir.

391. Piper, Charles V.
1906. Flora of the State of Washington. Contrib. U.S. Natl. Herb., v. 11, 637 pp., illus.

392. __________ and Beattie, R. Kent.
1915. Flora of the northwest coast, including the area west of the summit of the Cascade Mountains, from the forty-ninth parallel south to the Calapooya Mountains on the south border of Lane County, Oregon. 418 pp. Lancaster, Pa.: Press of the New Era Printing Co.

393. Plummer, Fred G.
1900. Mount Rainier Forest Reserve, Washington. U.S. Geol. Survey 21st Ann. Rpt. 1899-1900, Pt. 5, Forest Reserves: 81-143, illus.

394. __________
1902. Forest conditions in the Cascade Range between the Washington and Mount Rainier Forest Reserves. U.S. Geol. Survey Prof. Paper 6, 42 pp., illus.

This report covers those areas comprising Tps. 19 to 28 N. and from R. 9 E. eastward to the Columbia River. The proportion and amounts of timber species on these areas are treated in detail in descriptions of the several watersheds.

Pacific silver fir is found in the subalpine fir zone which ranges in elevation from 5,000 to 6,000 feet at latitude 45°30'. Its associates are subalpine fir, noble fir, mountain hemlock, Alaska-cedar, and western hemlock. At latitude 47°30' Pacific silver fir occurs within the lodgepole pine zone. Its associates here are lodgepole pine, western white pine, Engelmann spruce, noble fir, western larch, Alaska-cedar, and western yew. "Wind shake" is one of the greatest defects of Pacific silver fir in these zones. Trees exhibit wide seams from their bases almost to their tops.

395. __________
1912. Lightning in relation to forest fires. U.S. Dept. Agr. Forest Serv. Bul. 111, 39 pp., illus.

396. Pope, Robert B.
1957. The role of aerial photography in the current balsam woolly aphid outbreak. Forestry Chron. 33: 263-264.

397. ______
1958. Final report, cooperative evaluation survey of Chermes damage, Mount St. Helens, Washington, 1957. 25 pp., illus. Unpublished report on file U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta.

Major landowners in the Mount St. Helens area of Washington cooperated in a survey designed to obtain a reliable estimate of the total amount of dead and heavily damaged true firs and establish a base from which to measure future trends. Damage from the balsam woolly aphid has been severe in this vicinity. Estimates were obtained by combining interpretation of large-scale aerial photographs with field checks using standard statistical techniques. Within the 413,000-acre area surveyed were 6 billion board feet of true fir timber of which 1,765 million board feet were trees classed as dead or heavily damaged. True fir volumes averaged 30,000 board feet per acre made up of two-thirds silver fir and one-third noble fir. Approximately 9,000 board feet per acre were within trees classed as dead or heavily damaged. Silver fir constituted 100 percent of the true fir volume killed or heavily damaged by Chermes, 90 percent of the volume with light-to-moderate damage, and 50 percent of the undamaged volume. Thirty percent of the total volume of all species in the stands sampled was Pacific silver fir.

398. Prebble, M. L., and Graham, K.
1945. The current outbreak of defoliating insects in coast hemlock forests of British Columbia. Part I. Description of outbreak and damage. Part II. Factors of natural control. Brit. Columbia Lumberman 29(2): 25-27, 42, 44, 46, 48; 29(3): 37-39, 88, 90, 92, illus.

The black-headed budworm, *Peronea variana*, was the principal cause of defoliation damage to the western hemlock, mountain hemlock, and Pacific silver fir forests of northern Vancouver Island and the Queen Charlotte Islands from 1940-44. Virus diseases were primarily responsible for reducing the budworm populations in 1944; however, the populations of three other insect species increased markedly in 1944. Generally reduced increment, top-kill, and bud and twig mortality resulted from periods of defoliation; Pacific silver fir suffered less defoliation damage than either of the hemlocks.

The insect outbreaks, resulting defoliation damage, and life histories of the participating insect species are presented in Part I. The principal factors of natural control and their influences on the 1940-44 insect outbreak are described in Part II.

399. ______ and Graham, K.
1957. Studies of attack by ambrosia beetles in softwood logs on Vancouver Island, British Columbia. Forest Sci. 3: 90-112, illus.

Density of attack and damage by several species of ambrosia beetles on blocks sectioned from 630 Douglas-firs, western hemlocks, and Pacific silver firs between 1942 and 1945 were found to vary with time of felling, period of exposure, tree species, beetle species, and between logs from different and the same trees. Pacific silver fir logs felled in April to June had few attacks during the first season of exposure. However, these logs and those felled during July through January were moderately to heavily attacked when left in the woods until the following May or June.

The ambrosia beetles causing the damage in these studies are *Platypus wilsoni* Swaine, *Trypodendrom lineatum* (Oliver), *Gnathotrichus sulcatus* Lec., *Gnathotrichus retusus* Lec., and *Xyleborinus tsugae* Swaine. Each species of beetles exhibited distinctive and consistent patterns of attack in relation to season and felling date.

400. Prentice, R. M.
1962. Forest Lepidoptera of Canada. Recorded by the Forest Insect Survey, v. 2 - Nycteolidae, Noctuidae, Notodontidae, Liparidae. Canada Dept. Forestry Forest Ent. & Path. Branch Bul. 128, 281 pp., illus.

Lists 12 species that attack Pacific silver fir.

401. ——————
1963. Forest Lepidoptera of Canada. Recorded by the Forest Insect Survey, v. 3 - Lasiocampidae, Thyatiridae, Drepanidae, Geometridae. Canada Dept. Forestry Forest Ent. & Path. Branch Pub. 1013, pp. 283-543, illus.

Lists 28 species that attack Pacific silver fir.

402. Preston, Richard J., Jr.
1961. North American trees (exclusive of Mexico and tropical United States). Ed. 2, 395 pp., illus. Ames: Iowa State College Press.

403. Querengässer, von F.
1953. Beiderseits der Kaskaden-kammlinie. Forstarchiv 24: 48-58.

404. Raabe, Robert D.
1962. Host list of the root rot fungus, *Armillaria mellea*. Hilgardia 33(2): 25-88.

Armillaria mellea has been reported on Pacific silver fir in the United States and in Canada.

405. Randall, Warren R.
1958. Manual of Oregon trees and shrubs. 234 pp., illus. Corvallis: Oregon State College Cooperative Association.

406. Record, Samuel J.
1914. Identification of the economic woods of the United States; including a discussion of the structural and physical properties of wood. 117 pp., illus. New York: John Wiley & Sons, Inc.

407. ——————
1934. Identification of the timbers of temperate North America; including anatomy and certain physical properties of wood. 196 pp., illus. New York: John Wiley & Sons, Inc.

408. —————— and Hess, Robert W.
1943. Timbers of the new world. 640 pp., illus. New Haven: Yale University Press.

409. Rehder, Alfred.
1940. Manual of cultivated trees and shrubs hardy in North America. Ed. 2, 996 pp., illus. New York: The Macmillan Co.

410. Rhoads, Arthur S., Hedgcock, George G., Bethel, Ellsworth, and Hartley, Carl.
1918. Host relationships of the North American rusts, other than Gymnosporangiums, which attack conifers. Phytopathology 8: 309-352.

Peridermium balsameum Peck occurs as a leaf rust on Pacific silver fir.

411. Roach, Archibald W.
1952. Phytosociology of the Nash Crater lava flows, Linn County, Oregon. Ecol. Monog. 22: 169-193, illus.

A report on a phytosociologic study made of several communities developing on a series of different, young, volcanic substrates. The study area is at an elevation of 3,200 to 4,200 feet at the head of the McKenzie River in the central Oregon Cascades. Pacific silver fir is found in the *Pseudotsugeto-abietum grandis* association. This association occupies the most mesic substrate of the five associations described as growing on the young substrates: grayer, rounded block basalts with a high proportion of volcanic sand and ash mixed in and on scoria cones. It is represented in the reproduction and 3- to 12-inch size classes.

Pacific silver fir is an important constituent of the Douglas-fir—western hemlock forest bordering the volcanic deposits on the west and north. It was found in all size classes, except 24+ inches in diameter, and attained a frequency of 83 percent and a basal area of 7 percent of the total. Pacific silver fir and western hemlock are considered to be the climax species in this association.

412. Rochester, G. H.
1933. The mechanical properties of Canadian woods, together with their related physical properties. Canada Dept. Int. Forest Serv. Bul. 82, 88 pp., illus.

413. Roff, J. W., and Eades, H. W.
1959. Deterioration of logging residue on the British Columbia coast (western hemlock, amabilis fir, and Sitka spruce). Canada Dept. North. Aff. & Natl. Resources Forestry Branch F.P.L. Tech. Note 11, 38 pp., illus.

Annual observations of logging residues (no pieces shorter than 8 feet or less than 6 inches in top diameter included) revealed that Pacific silver fir was less decay resistant than either western hemlock or Sitka spruce, particularly 1 to 2 years following logging. At the end of 4 years, 72.9 percent of the original volume of Pacific silver fir residue exhibited a partial or complete disintegration of wood structure, and 98.2 percent of the original volume exhibited all manifestations of decay including discolorations and disintegration of structure. Generally, the relative importance of brown and white rots in the annual deterioration of Pacific silver fir residue varied by year since logging: brown rots accounted for 65, 11, and 60 percent of all decay in the second, third, and fourth years following logging; white rots accounted for the remainder. Specifically, the most important fungal organisms on Pacific silver fir residues were *Stereum sanguinolentum* and *Fomes annosus*, both white rots, which caused 41 and 47 percent, respectively, of all the decay.

In general, severity of residue deterioration was directly associated with high moisture content within the wood, lower elevations, damage by ambrosia beetles *(Trypodendron cavifrons)*, and amount of decay prior to logging. The amounts of sapwood in the three study species showed no relationships to the amounts or rates of decay, and the rate of sapwood decay was similar to that of heartwood.

On the basis of this study, salvage of western hemlock and Pacific silver fir residue should be done within 2 years of logging.

414. Rohmeder, E.
1961. Praktische Anwendungsmöglichkeiten forstgenetischer Forschungsergebnisse. Schweiz. Ztschr. für Forstw. (Jour. Forestry Suisse) 112: 43-71, illus.

415. Ross, Charles R.
1957. Trees to know in Oregon. Oreg. Ext. Serv. Bul. 697 (rev.), 88 pp., illus. Corvallis: Oregon State College Press.

416. Rowe, J. S.
1959. Forest regions of Canada. Canada Dept. North. Aff. & Natl. Resources Forestry Branch Bul. 123, 71 pp., illus. (Revision of "A forest classification for Canada," by W. E. D. Halliday, Canada Dept. North. Aff. & Natl. Resources Bul. 89, 1937.)

Pacific silver fir is represented in the "Interior Subalpine Section" (SA. 2) and "Coastal Subalpine Section" (SA. 3) of the "Subalpine Forest Region" and in the "Southern Pacific Coast Section" (C. 2) and "Northern Pacific Coast Section" (C.3) of the "Coast Forest Region."

417. Rübel, E.
1915. Die auf der "Internationalen pflanzengeographischen Exkursion" durch Nordamerika 1913 kennengelernten Pflanzengesellschaften. Bot. Jahrb. 53, Bleib. 116: 3-36, illus.

418. Rudinsky, J. A.
1957. Notes on the balsam woolly aphid. Weyerhaeuser Timber Co., 12 pp., illus.

A limited review of the information available on the balsam woolly aphid, including preventive practices and control measures likely to be of some merit in the Northwest and some recent European studies of interest.

Adelges piceae had not been reported on Pacific silver fir previous to the heavy infestation discovered in 1954. Swelling or "gouting" was much more pronounced in Pacific silver fir than in the European firs, but the effects of the aphid were similar to those described for balsam fir. Trees of any age can be attacked and any part of the tree infested. Crowns of dominant and codominant Pacific silver firs and those on the edge of the stand or in the open seem to be particularly preferred, possibly because of a positive phototropic behavior of the insect. On mature and overmature silver fir, crown infestation may be most important; on young trees, a stem infestation.

Preventive measures suggested include avoiding planting of infested seedlings, winter cutting and removal of timber, short rotation ages, and replacement of silver fir with other species. Control by natural predators offers the most promise, much more so than control by silvicultural or chemical means.

419. __________ and Vité, J. P.
1959. Certain ecological and phylogenetic aspects of the pattern of water conduction in conifers. Forest Sci. 5: 259-266, illus.

Presents five water-conducting systems and discusses their ecological and phylogenetic significance. These systems are: spiral ascent, turning right; spiral ascent, turning left; interlocked ascent; sectorial, winding ascent; and sectorial, straight ascent.

All investigated species of true fir (including Pacific silver fir), larch, and spruce and the hard pines possess the spiral-ascent, turning-right system, which of all the systems exhibits the greatest water distribution to the crown. The inherent advantage of this system is that it decreases the danger that loss of individual roots will decrease the water supply of entire tree sectors. The authors suggest that tree species with this system may respond quickly to environmental changes and thus become better competitors than other tree species.

420. Ruth, Robert H.
[1963]. Site preparation in the high elevation types of the west Cascades and coastal forests; the conditions under which site preparation is required and the methods now available. In Western Reforestation 1962. West. Forestry & Conserv. Assoc. West. Reforestation Coordinating Comm. Proc. 1962: 14-16.

421. St. John, Harold, and Hardin, Edith.
1929. Flora of Mt. Baker. Mazama 11: 52-102, illus.

422. __________ and Warren, F. A.
1937. The plants of Mount Rainier National Park, Washington. Amer. Midland Nat. 18: 952-985.

423. Sargent, C. S.
1885. The woods of the United States. With an account of their structure, qualities, and uses. With geographical and other notes upon the trees which produce them. 203 pp., illus. New York: D. Appleton & Co.

This valuable book describes the physical appearances and properties of 412 species of American tree woods and rates them by their specific gravity, percentage of ash, relative approximate fuel value, coefficient of elasticity, modulus of rupture, resistance to pressure, and weight per cubic foot. The wood samples used in this study were obtained from the American Museum of Natural History collection.

Pacific silver fir: "Wood light, hard, not strong, close grained, compact; bands of small summer cells broad, resinous, dark-colored, conspicuous, medullary rays numerous thin; color light brown. The sap-wood nearly white."

424. Sargent, Charles Sprague.
1898. The silva of North America. v. 12, 144 pp., illus. Boston, New York: Houghton Mifflin Co.

A description of the botanical characteristics, range, and synonymy of North American conifers with plates illustrating the botanical features of cones, flowers, and foliage.

Pacific silver fir often reaches 250 feet in height, bark of the trunk is usually thin, smooth, and pale or silvery white. Winter buds are nearly globose with closely imbricated purple scales thickly coated with resin. Leaves are flat, deeply grooved, dark green, and lustrous on the upper surface and silvery white on the lower. The cones are oblong, deep purple, from 3 to 6 inches in length and 2 to 2-1/2 inches in diameter, and cone scales are nearly as long as they are broad.

Sargent reports on a supposed natural hybrid between Pacific silver fir and subalpine fir found by him in a stand of the two species growing on a ridge of the Olympic Mountains which separates the Solduc [sic] and Quillyhute [sic] rivers. The hybrid had the slender, spirelike head and foliage of subalpine fir and the cones of Pacific silver fir.

425. Sargent, Charles Sprague.
1933. Manual of the trees of North America (exclusive of Mexico). Ed. 2, 910 pp., illus. Boston, New York: Houghton Mifflin Co. (Reprinted 1961, 2 v. New York: Dover Publications, Inc.)

A classical dendrological reference containing botanical and gross wood anatomy descriptions along with botanical ranges and uses of native North American trees.

426. Schmitz, Henry.
1916. Preliminary note on the occurrence of *Peridermium balsameum* in Washington. Phytopathology 6: 369-371.

Peridermium balsameum Peck. was found in abundance on grand fir seedlings, and *Peridermium pseudo-balsameum* (D. & H.) Arth. was provisionally identified on Pacific silver fir needles.

427. Schmidt, R. L.
1955. Some aspects of western red cedar regeneration in the coastal forests of British Columbia. Brit. Columbia Forest Serv. Res. Notes 29, 10 pp., illus.

428. __________
1957. The silvics and plant geography of the genus *Abies* in the coastal forests of British Columbia. Brit. Columbia Forest Serv. Tech. Pub. T. 46, 31 pp., illus.

The maximum abundance and development of Pacific silver fir occurs in British Columbia in areas with high annual precipitation. The species is rare or absent in coastal areas with warm dry summers--probably because of the high fire frequency of those areas. The species is able to occupy a wide range of site conditions although its best growth occurs on deep, well-drained soils supplied with abundant but not excessive moisture. Its poorest growth occurs on poorly drained sites with excessive moisture. The species is able to grow even when the root systems are confined to organic soil layers.

Pacific silver fir, if not the most shade-tolerant species of the coastal conifers, is at least as tolerant as western hemlock or western redcedar. The average maximum age the species attains is between 400 and 500 years on the best sites, 250 and 350 years on the poorer sites.

Pacific silver fir seed is large and has a high rate of fall so the seed is not adapted to long-distance wind dispersion. Since the seeds are not effectively distributed by birds and mammals, the species is a slow migrator and takes 700 to 800 years to invade new areas if fire is excluded. There is considerable evidence suggesting that Pacific silver fir has not fully inhabited its potential range because it is poorly equipped for rapid migration and enough postglacial time has not elapsed to offset this shortcoming.

429. Schmidt, R. L.
1957. E. P. 368--The adaptability of tree species to forest sites. In Forest Research Review 1956. Brit. Columbia Forest Serv. Pub., p. 13.

Douglas-fir, western hemlock, western redcedar, Pacific silver fir, grand fir, and Sitka spruce were seeded in a sword fern association and in a salmonberry-fern association on the west coast of Vancouver Island. After three growing seasons grand fir and Douglas-fir survived best. The poor performance of the other four species was attributed to low germinative capacity and unfavorable seedbed conditions.

430. ________
1958. E. P. 368--The adaptability of tree species to forest sites. In Forest Research Review, Year Ended March 1958. Brit. Columbia Forest Serv. Pub., p. 13.

Planted Pacific silver fir seedlings had 90-percent survival after one growing season on a slash-burned area at Ucluelet.

431. ________
1958. E. P. 482--Climate and the altitudinal distribution of conifers. In Forest Research Review, Year Ended March 1958. Brit. Columbia Forest Serv. Pub., pp. 18-19.

An abrupt decrease in the length of frost-free periods, which occurred 500 feet above the altitudinal limits of Douglas-fir, western hemlock, and western redcedar, is considered a climatic boundary. However, this climatic boundary does not control the altitudinal ranges of the upland species in the Ek Valley on Vancouver Island. Subalpine fir and mountain hemlock occur from 2,300-foot elevation to tree line, and Pacific silver fir and Alaska-cedar grow from the valley bottom to over 5,000-foot elevation.

432. ________
1959. E. P. 368--The adaptability of tree species to forest sites. In Forest Research Review, Year Ended March 1959. Brit. Columbia Forest Serv. Pub., p. 23.

Measurements of several coniferous species planted on two slash-burned areas at Ucluelet revealed Douglas-fir performed better than the other species with respect to survival, initial growth, and health. Pacific silver fir had the poorest height growth of all the conifers and only fair survival.

433. ________
1960. E. P. 368--The adaptability of tree species to forest sites. In Forest Research Review, Year Ended March 1960. Brit. Columbia Forest Serv. Pub., pp. 10-11, illus.

Several species of conifers were planted in areas that originally supported an uneven-aged mixture of western hemlock and Pacific silver fir. These species were subsequently compared in terms of survival, growth, and health. Douglas-fir, Sitka spruce, Port-Orford-cedar, and western hemlock were rated good, western redcedar and grand fir were rated fair, and Pacific silver fir was rated poorest--despite the fact it was a primary species in the former stand.

434. Schmidt, R. L.
1960. E. P. 482--Climate and the altitudinal distribution of conifers. In Forest Research Review, Year Ended March 1960. Brit. Columbia Forest Serv. Pub., pp. 15-18, illus.

Western redcedar pollen dispersal began around the middle of April, followed by Douglas-fir on May 2, western hemlock on May 7, grand fir on May 15, and Pacific silver fir on May 19. There is little or no difference between the species in the time of beginning of radial growth. Radial growth began before pollen dispersion in the two true firs, indicating either faulty techniques or a generic behavioral difference.

435. ________
1961. E. P. 368--The adaptability of tree species to forest sites. In Forest Research Review, Year Ended March 1961. Brit. Columbia Forest Serv. Pub., pp. 10-11.

The average heights of the conifers planted at Ucluelet Area No. 1 after five growing seasons were: Port-Orford-cedar, 55 inches; Douglas-fir, 53 inches; western hemlock, 11 inches; and Pacific silver fir, 11 inches. Heights at 3 years at Area No. 2 were: Douglas-fir, 55 inches; western hemlock, 51 inches; Sitka spruce, 50 inches; Port-Orford-cedar, 42 inches; grand fir, 30 inches; western redcedar, 26 inches; and Pacific silver fir, 12 inches.

436. ________
1962. E. P. 368--The adaptability of tree species to forest sites. In Forest Research Review, Year Ended March 1962. Brit. Columbia Forest Serv. Pub., pp. 11-12.

437. Scott, David R. M.
1962. The Pacific Northwest region. In Regional Silviculture of the United States, ed. by John W. Barrett. Pp. 503-570, illus. New York: The Ronald Press Co.

Discusses the physical environment and major forest type groups with the primary emphasis on description of typical sites of these groups, their place in ecological succession, growth rates, rotation ages, silvicultural practices, and damaging agents. The Pacific silver fir-hemlock cover type group (climax) succeeds the subclimax Douglas-fir–noble fir–white pine type group in the Canadian Zone on the western slopes of the Cascades. Pacific silver fir is also a frequent component of stands in the Humid Transition Zone.

438. ________
1962. Plant associations of western Washington. Univ. Wash. Arboretum Bul. 25(1): 11-14, 26.

In the Humid Transition Zone of western Washington, Pacific silver fir is a prominent species on higher elevation sites within the western hemlock–western redcedar association and hemlock–cedar–spruce associations. The climax association of the Canadian Zone is distinguished by the dominance of Pacific silver fir.

439. Serenius, R. S.
1956. Sulphite pulping of western hemlock, balsam and spruce. Pulp & Paper Mag. Canada 57(9): 133-137, illus.

Author's abstract: "The sulphite pulping properties of western hemlock, Sitka spruce and balsam (grand and Pacific silver fir) have been studied using a small experimental digester. These species are compared at constant permanganate number, cooking schedule and screenings content. For each species there is shown to exist a 'critical' permanganate value at which important changes in strength and yield occur. The obtained data are capable of many practical applications as indicated by examples."

440. Shantz, H. L, and Zon, Raphael.
1924. Natural vegetation, sect. E. Pt. 1. The physical basis of agriculture. Atlas of American Agriculture. U.S. Dept. Agr., 29 pp., illus.

441. Shaw, Charles Gardner.
1958. Host fungus index for the Pacific Northwest. I. Hosts. Wash. Agr. Expt. Sta. Cir. 335, 127 pp.

Lists 61 species of fungi known to occur on Pacific silver fir.

442. __________
1958. Host fungus index for the Pacific Northwest fungi. Wash. Agr. Expt. Sta. Cir. 336, 237 pp.

443. Shea, Keith R.
1960. Deterioration--a pathological aspect of second-growth management in the Pacific Northwest.* Weyerhaeuser Timber Co. Forestry Res. Center Forestry Res. Note 28, 16 pp.

Brings together pertinent information on the deterioration of injured coniferous forest trees in the Pacific Northwest. Discusses decay associated with mechanical injury, windthrow, fire, and insects. Pacific silver fir is included.

444. __________
1960. Yellow laminated root rot of Douglas-fir: A literature review. Weyerhaeuser Timber Co. Forestry Res. Center, 18 pp.

Poria weirii has been isolated from Pacific silver fir host.

445. __________ and Johnson, Norman E.
1957. Analysis of deterioration of Chermes-killed Pacific silver fir. Weyerhaeuser Timber Co. Forestry Res. Center, 12 pp.

Reviews the findings of other studies on the agents and factors causing and correlated with deterioration losses in Chermes-killed Pacific silver fir. Objectives and general methods for proposed research are presented.

446. __________ Johnson, Norman E., and McKee, Samuel.
1962. Deterioration of Pacific silver fir killed by the balsam woolly aphid. Jour. Forestry 60: 104-108, illus.

The study's purpose was to determine "(1) insects and fungi found in dead and deteriorating silver fir killed by the aphid; (2) rate and extent of deterioration; (3) yield and quality of representative pulps; and (4) characteristics of silver fir dead for varied periods up to five years."

Ambrosia beetles were the most numerous of the wood-boring insects in trees dead 1 year or less. Their activity was concentrated mainly in the butt logs of the trees. The species involved included *Gnathotrichus sulcatus*, *Trypodendron lineatum*, and *Platypus wilsoni*. The horntails (Siricidae) and round-headed borers *(Monochamus oregonensis* and *Stenocorus lineatus)* attacked the middle and top of the sample trees. Bark beetle *(Pseudohylesinus grandis)* attacks were found in all portions of the trees but concentrated on the upper and middle portions. *Pseudohylesinus granulatus* attacks were located in the butt and lower bole.

Brown rot *(Fomes pinicola)* was the most common wood-destroying fungus, followed in importance by a white rot *(Polyporus abietinus)* and patchy rot *(Stereum chaillettii)*. Mycelial fans of shoestring root rot *(Armillaria mellea)* occurred at the base of half of the trees dead less than 1 year and was evident in all dead trees after 2 years. It caused negligible loss of merchantable volume, however.

The average depth of penetration of incipient and advanced decay increased with height above the ground for each mortality class (living, dead 1 year or less, dead 2 or 3 years, dead 3 to 5 years). The butt log was least affected by decay. Deterioration of study trees averaged 13 percent of the merchantable cubic volume per year and reached an average of 53 percent of the cubic volume and 64 percent of the board-foot volume in 3 to 5 years.

Unbleached sulfite pulps from trees dead 3 to 5 years were characterized by low alpha cellulose, low viscosity, high potassium hydroxide solubility, and low physical strength. The pulp yields varied from tree to tree with no correlation with elapsed time after tree death. Unbleached kraft pulp yields decreased rapidly with time after death. Pulp quality decreased rapidly with time regardless of pulping process.

Several characteristics of the tree crown and lower bole may be useful indices for salvage. A table is included showing the relationship of percentage of foliage persisting, percentage of branchlets broken off, phloem color and decay, bark tightness, sapwood color and decay, and percent of trees attacked by three species of insects and by shoestring root rot to number of years the tree has been dead.

447. Sigafoos, R. S., and Hendricks, E. L.
1961. Botanical evidence of the modern history of Nisqually Glacier, Washington; a description of botanical methods used to determine dates of recession of three glaciers at Mount Rainier, Washington. U.S. Geol. Survey Prof. Paper 387-A, 20 pp., illus.

448. Siggins, Howard W.
1933. Distribution and rate of fall of conifer seeds. Jour. Agr. Res. 47: 119-128, illus.

The average rate of fall of Pacific silver fir seed is 4.95 feet per second. The average weight of good seed is 0.75 gram.

449. Silen, Roy R., and Woike, Leonard R.
1959. The Wind River Arboretum, 1912-1956.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Paper 33, 50 pp., illus.

Two lots of Pacific silver fir are represented among the 24 true firs surviving in this southwestern Washington arboretum. A growth index of 0.41 (based on 1.00 for indigenous Douglas-fir) illustrates silver fir's slow growth in the area. No significant insect or climatic damage to the species has occurred.

450. Silver, G. T.
1959. The balsam woolly aphid, *Adelges piceae* (Ratz). Brit. Columbia Canada Dept. Agr. Div. Forest Biol. Bimo. Prog. Rpt. 15(1): 3.

451. Society of American Foresters.
1954. Forest cover types of North America (exclusive of Mexico). 67 pp., illus. Washington, D. C.

Pacific silver fir is a major component of type 226, Pacific silver fir–hemlock, although it may not predominate. This widespread but discontinuous type extends from southern Alaska to southern Oregon. In Alaska and British Columbia, it ranges from near sea level to 4,000 feet; in Washington and Oregon, the type ranges from 1,500 to 5,000 feet in elevation. It is bounded by the Douglas-fir and western redcedar–hemlock types at lower elevations and by the alpine types at higher elevations.

Pacific silver fir is also found in types 229 (Pacific Douglas-fir), 230 (Douglas-fir–western hemlock), 225 (Sitka spruce–western hemlock), 224 (western hemlock), 223 (Sitka spruce), and 205 (mountain hemlock–subalpine fir).

452. Sowder, A. M.
1961. 1960 Christmas tree data. Jour. Forestry 59: 829-830.

453. Spada, Benjamin.
1962. Forest statistics for Clallam County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 145, 26 pp., illus.

In 1960, estimated volumes were 1,552 million board feet (Scribner rule) of Pacific silver fir sawtimber and 307 million cubic feet of growing stock on commercial forest land in Clallam County.

454. ______
1962. Forest statistics for Jefferson County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 144, 26 pp., illus.

In 1960, estimated volumes were 4,201 million board feet (Scribner rule) of Pacific silver fir sawtimber and 781 million cubic feet of growing stock on commercial forest land in Jefferson County.

455. ______
1962. Forest statistics for King County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 143, 27 pp., illus.

In 1960, estimated volumes were 3,422 million board feet (Scribner rule) of Pacific silver fir sawtimber and 759 million cubic feet of growing stock on commercial forest land in King County.

456. Spada, Benjamin.
1962. Forest statistics for Pierce County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 141, 26 pp., illus.

In 1959, estimated volumes were 1,113 million board feet (Scribner rule) of Pacific silver fir sawtimber and 270 million cubic feet of growing stock on commercial forest land in Pierce County.

457. __________ and Bones, James T.
1957. Forest statistics for Snohomish County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 128, 30 pp., illus.

In 1955, estimated volumes were 4,488 million board feet (Scribner rule) of Pacific silver fir sawtimber and 927 million cubic feet of growing stock on commercial forest land in Snohomish County.

458. __________ and Usher, Jack H.
1955. Forest statistics for Yakima County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 121, 29 pp., illus.

In 1954, estimated volumes were 797 million board feet (Scribner rule) of Pacific silver fir sawtimber and 258 million cubic feet of growing stock on commercial forest land in Yakima County.

459. Spaulding, Perley.
1956. Diseases of North American forest trees planted abroad; an annotated list. U.S. Dept. Agr. Agr. Handb. 100, 144 pp.

460. Sprague, F. LeRoy, and Hansen, Henry P.
1946. Forest succession in the McDonald Forest, Willamette Valley, Oregon. Northwest Sci. 20: 89-98, illus.

461. Staebler, George R.
1958. Silvical characteristics of noble fir.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Silvical Ser. 5, 12 pp., illus.

462. Steele, Robert W., and Worthington, Norman P.
1955. Increment and mortality in a virgin Douglas-fir forest.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 110, 6 pp., illus.

463. Stein, William I.
1951. Germination of noble fir and silver fir seed on snow. Jour. Forestry 49: 448-449, illus.

Germination of noble and silver fir seeds was observed to take place on the snow. Very few of the resulting seedlings managed to establish their root tips in the soil. Those that did were shallow rooted and possessed crooked and elongated stems. It was considered extremely doubtful they could survive a normal summer. These findings suggest that broadcast sowing of true fir seed on snow will be unsuccessful.

464. Stokes, W. B.
1925. Canadian softwoods. Canada Dept. Int. Forestry Branch Cir. 19, 13 pp.

465. Stone, Herbert.
1904. The timbers of commerce and their identification. 311 pp., illus. London: W. Rider & Son Ltd.

466. Streets, R. J.
1962. Exotic forest trees in the British Commonwealth. 765 pp., illus. Oxford: Clarendon Press.

467. Sudworth, Geo. B.
1893. On legitimate authorship of certain binomials with other notes on nomenclature. Torrey Bot. Club Bul. 20: 40-46.

468. Sudworth, George B.
1897. Nomenclature of the arborescent flora of the United States. U.S. Dept. Agr. Div. Forestry Bul. 14, 417 pp.

469. ———
1908. Forest trees of the Pacific slope. U.S. Dept. Agr. Forest Serv., 441 pp., illus.

Pacific silver fir, *Abies amabilis* (Loud.) Forbes, "white" or "silver" fir, is a "straight tree, clear of branches for from 50 to 100 feet in close, dense stands. Its height in favorable situations is from 150 to 180 feet, sometimes 200 feet, and its diameter from 3 to 5 feet, or rarely 6 feet. In less favorable sites the height is from 75 to 100 feet and from 18 to 30 inches in diameter.... The spherical resin-covered buds of this fir are characteristic.... The dark purple cones...about 4 to 5-1/2 inches in length by 2-1/4 to 2-1/2 inches in thickness.... Wood...light but considerably heavier than that of the white or grand firs...fine-grained...one of the best of the soft firs."

"A most striking characteristic is its smooth, ashy-gray, unbroken bark, conspicuously marked with large chalky-white areas."

"Grows in well-drained, shallow, gravelly sand to moist, sandy loam, or in porous rocky soils; best on sandy loam; good drainage necessary, as is also abundant...soil moisture.... In pure, limited stands and small groups (Vancouver Island, Olympics, high levels in Cascades), but more commonly in mixture .... Prolific seeder. Some seed borne locally nearly every year...heavy seeding occurs at rather irregular intervals of 2 to 3 years. Seed...low rate of germination...vitality...transient."

470. ———
1927. Check list of the forest trees of the United States, their names and ranges. U.S. Dept. Agr. Misc. Cir. 92, 295 pp.

471. Suksdorf, William N., and Howell, Thomas.
1896. Flora of Mount Adams. Mazama 1: 68-97.

472. Sweeten, James Ross.
1961. A study of ray tracheids in hemlock and balsam from southwestern British Columbia. 35 pp., illus. Unpublished B.S.F. thesis on file Univ. Brit. Columbia.

Because of their different strength properties, a method was sought for distinguishing "hemlock" (western and mountain hemlocks) from "balsam fir" (Pacific silver, grand, and subalpine firs) which are presently sold indiscriminately as "hemlock" in the Vancouver area. Ray tracheids proved a reliable means of distinguishing the woods. Ray tracheids were found in all hemlock samples but in only one of the 200 balsam fir samples (subalpine fir). No reliable macroscopic method of identification was found, however. The theory that ray tracheids in some true firs are caused by injury was not confirmed in this study; none of the wood samples from injured true firs exhibited them.

473. Tarrant, Robert F., Isaac, Leo A., and Chandler, Robert F., Jr.
1951. Observations on litter fall and foliage nutrient content of some Pacific Northwest tree species. Jour. Forestry 49: 914-915.

The annual litter fall of Pacific silver fir is 1,582 pounds per acre (ovendry weight basis). A nutrient analysis of Pacific silver fir litter indicates the following quantities of nutrients, in pounds per acre, are deposited annually: nitrogen, 14.8; phosphorus, 1.9; potassium, 3.8; calcium, 14.5; magnesium, 0.9. The acidity (pH) of soil horizons developed under Pacific silver fir stands were Ao horizon, 3.77; 0- to 2-inch depth, 4.35; and 8- to 10-inch depth, 5.02.

474. Taylor, Raymond F.
1956. Alaska. In A World Geography of Forest Resources. Ed. by Stephen Haden-Guest, John K. Wright, and Eileen M. Teclaff for Amer. Geog. Soc. pp. 115-125, illus. New York: The Ronald Press Co.

475. __________ and Little, Elbert L., Jr.
1950. Pocket guide to Alaska trees. U.S. Dept. Agr. Agr. Handb. 5, 63 pp., illus.

Pacific silver fir is found near southeast tip of Alaska. It occurs on well-drained lower slopes of canyons, benches, and flats from sea level to an elevation of 1,000 feet. It attains a height of 75 feet.

476. Taylor, Walter P.
1922. A distributional and ecological study of Mount Rainier, Washington. Ecology 3: 214-236, illus.

477. Thickens, J. H., and McNaughton, G. C.
1916. Ground-wood pulp. Pt. 1. The grinding of cooked and uncooked spruce. Pt. 2. Substitutes for spruce in the manufacture of ground-wood pulp. U.S. Dept. Agr. Bul. 343, 151 pp., illus.

478. Thomas, Gerard M.
1957. Climate and growth rate as related to an outbreak of silver fir beetles.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 150, 5 pp., illus.

Abnormally warm and dry weather conditions existed immediately before and during the beetle outbreak. However, there was no positive correlation between climate (temperature and precipitation) and radial growth.

479. Thomas, Gerard M., and Wright, K. H.
1961. Silver fir beetles. U.S. Dept. Agr. Forest Pest Leaflet 60, 7 pp., illus.

The fir root bark beetles *Pseudohylesinus granulatus* (Lec.) and the silver fir beetle *P. grandis* Sw. are highly destructive to Pacific silver fir. This leaflet describes the beetles' appearance, their life cycles and habits, and evidences of their attack. Felling infested trees and either burning or spraying them with chemicals are ineffective control measures. Logging infested stands during the fall, winter, and spring reduces the beetle population and provides some control. *Armillaria mellea*, *Fomes annosus*, *Poria weirii*, and *Poria subacida* are root-rotting fungi, commonly associated with the bark beetle attacks.

480. Thomas, G. P.
1958. Studies in forest pathology XVIII. The occurrence of the Indian paint fungus, *Echinodontium tinctorium* E. and E., in British Columbia. Canada Dept. Agr. Forest Biol. Lab. Pub. 1041, 30 pp., illus.

A survey of the known hosts on 50 habitat types revealed Indian paint fungus is absent from 16 of these forest types despite the occurrence in them of one or more of its known hosts. The survey indicated the distribution and abundance of the fungus are directly influenced by summer climate and the inherent susceptibilities of its different hosts to infection. Indian paint fungus is indirectly influenced by altitude, topography, and the silvical characteristics of trees. High average summer temperatures in combination with high humidities and the proportion of the stem length of trees over which these atmospheric conditions prevail are also important.

True firs appear more susceptible to infection than hemlocks, spruces, or Douglas-firs. Pacific silver fir is infected by the fungus on 16 of the 24 habitat types in which it occurs. The infections were heaviest at heights above the midpoint of dominant trees. Trees intermediate or less in height often escaped infection. The author believes that the low degree of infection in understory Pacific silver fir is due to the cool atmospheric conditions that normally prevail near the ground. Conditions in the upper canopies high above the ground are more conducive to infections.

481. Thompson, Allen E.
1924. The forest resources of Washington. Univ. Wash. Forest Club Quart. 3(1): 19-32, illus.

482. Thompson, W. P.
1910. The origin of ray tracheids in the coniferae. Bot. Gaz. 50: 101-116.

Reports the occurrence of ray tracheids in a wounded root of Pacific silver fir.

483. ________
1912. Ray tracheids in Abies. Bot. Gaz. 53: 331-338.

Thompson describes ray tracheids found associated with wounds in Pacific silver fir and white fir and in uninjured wood of *Abies homolepis* and *A. veitchii.* Ray tracheids were also associated with degenerating cells or "ghosts" and with marginal parenchyma cells at the ends of some annual rings. Thompson concludes, "... ray tracheids were present in the ancestors of *Abies*, and have persisted sporadically in a few species, but in the majority have either degenerated or been transformed to parenchyma."

484. Timell, T. E.
1961. Isolation of galactoglucomannans from the wood of gymnosperms. TAPPI 44(2): 88-96.

485. Timell, Tore E.
1961. Characterization of four celluloses from the bark of gymnosperms. Svensk PappTidn. 64: 685-688.

Celluloses were isolated from barks of Pacific silver fir, Engelmann spruce, lodgepole pine, and ginkgo in yields of 38.1, 30.9, 30.4, and 37.6 percent, respectively.

486. ________
1961. Constitution of a glucomannan from the bark of amabilis fir *(Abies amabilis)*. Svensk PappTidn. 64: 744-747.

The glucomannan was isolated in a yield of 3 percent from the bark of Pacific silver fir. Its structure was discussed and found to be very similar to the corresponding polysaccharides found in wood of this and other species of gymnosperms.

487. ________
1961. Isolation of polysaccharides from the bark of gymnosperms. Svensk PappTidn. 64: 651-661.

The general chemical composition was determined for the whole bark of Pacific silver fir and Engelmann spruce.

488. ________
1961. The structure of an arabino-4-0-methylglucuronoxylan from the bark of amabilis fir *(Abies amabilis)*. Svensk PappTidn. 64: 748-750.

This water-soluble chemical was isolated in a yield of 2.1 percent from bark of Pacific silver fir. The structure of this bark xylan was described.

489. Trelease, William, and Gray, Asa, ed.
1887. The botanical works of the late George Engelmann, collected for Henry Shaw. 548 pp., illus. Cambridge, Mass.: John Wilson & Son.

A complete collection of Engelmann's botanical publications assembled as a memorial. In an 1880 number of the Gardener's Chronicle, Engelmann related the discovery of *Abies amabilis* by him, Sargent, and Parry on Silver Mountain, near Fort Hope, Frazer River, at an altitude of 4,000 to 5,500 feet.

490. Trappe, James M.
1960. Some probable mycorrhizal associations in the Pacific Northwest. II. Northwest Sci. 34: 113-117.

An association, probably mycorrhizal, was noted between *Boletus edulis* Bull. ex Fries and Pacific silver fir and western hemlock on the east slope of the Cascade Range in Washington at an elevation of 3,000 feet.

491. ________
1961. Some probable mycorrhizal associations in the Pacific Northwest. III. Northwest Sci. 35: 91-94.

A probable mycorrhizal association was noted between Pacific silver fir and *Lactarius sanguifluus* (Paulet ex) Fries on the west slope of the Cascade Range in southern Oregon at 3,000-foot elevation. Also noted was an association with *Russula delica* which occurs throughout the coniferous forests from sea level to at least 4,500-foot elevation.

492. ________
1962. Fungus associates of ectotrophic mycorrhizae. Bot. Rev. 28: 538-606.

Fungal species reported in the literature to form mycorrhizal associations with Pacific silver fir are *Boletus edulis*, *Cenococcum graniforme*, *Lactarius deliciosus*, *L. sanguifluus*, *Russula delica*, *R. emetica*, and *Xerocomus pulverulentus*.

493. Troll, C.
1955. Der Mount Rainier und das mittlere Cascaden-Gebirge. Erdkunde 9(4): 264-274, illus.

494. Tunstell, George.
1956. Canada. In A World Geography of Forest Resources. Ed. by Stephen Haden-Guest, John K. Wright, and Eileen M. Teclaff for Amer. Geog. Soc. pp. 127-147, illus. New York: The Ronald Press Co.

495. Twerdal, Melvin P., and Minore, Don.
1955. Forest statistics for Thurston County, Washington.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 123, 27 pp., illus.

496. Twerdal, M. P., and MacLean, C. D.
1957. Forest statistics for Tillamook County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 130, 34 pp., illus.

It was estimated in 1955 there were less than 0.5 million board feet (Scribner) and 0.5 million cubic feet of Pacific silver fir sawtimber and growing stock, respectively, in Tillamook County.

497. Underwood, G. R., and Balch, R. E.
1964. A new species of *Pineus* (Homoptera: Adelgidae) on *Abies*. Canad. Ent. 96: 522-528, illus.

A new anholocyclic species, *Pineus abietinus*, found on Pacific silver fir and grand fir, is described.

498. U.S. Agricultural Research Service.
1960. Index of plant diseases in the United States. U.S. Dept. Agr. Agr. Handb. 165, 531 pp., illus.

499. U.S. Forest Service.
1908. Amabilis fir. *Abies amabilis* (Loud.) Forb. U.S. Dept. Agr. Forest Serv. Silvical Leaflet 22, 3 pp.

500. ________
1932. Key to native conifers and yew of Oregon. Unpublished leaflet on file, U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 4 pp.

501. U.S. Forest Service.
1936. Forest type map, State of Oregon (NW. quarter), 1 inch = 4 miles. Prepared by the Forest Survey staff, U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta.

502. ________
1936. Forest type map, State of Oregon (SW. quarter), 1 inch = 4 miles. Prepared by the Forest Survey staff, U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta.

503. ________
1936. Forest type map, State of Washington (NW. quarter), 1 inch = 4 miles Prepared by the Forest Survey staff, U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta.

504. ________
1936. Forest type map, State of Washington (SW. quarter), 1 inch = 4 miles. Prepared by the Forest Survey staff, U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta.

505. ________
1948. Woody-plant seed manual. U.S. Dept. Agr. Misc. Pub. 654, 416 pp., illus.

Pacific silver fir flowers in the spring, cones ripen in September, and seed dispersal occurs in October. Good seed crops occur every 2 to 3 years. A bushel of cones may yield 48 ounces of seed and there are 8,200 to 14,900 cleaned seed per pound. Eight samples of commercial seed averaged 45 percent sound and 91 percent pure.

506. ________
1950. Annual report, 1949.* Pac. NW. Forest & Range Expt. Sta., 62 pp.

A forest insect survey revealed 127,000 acres of Pacific silver fir in Washington and Oregon were infested by the fir engraver beetles *(Pseudohylesinus* sp.). Studies were initiated to evaluate the problem and to determine the habits of the insects, characteristics of their attack, and factors responsible for the outbreak.

507. ________
1952. Annual report, 1951.* Pac. NW. Forest & Range Expt. Sta., 51 pp.

The fir engraver beetle *(Pseudohylesinus* sp.) infestation in Pacific silver fir expanded primarily on the west side of the Olympic Peninsula. Current investigations suggested that stand age, vigor and species composition, and soil composition and structure are important factors in an outbreak. Root-rotting fungi were closely associated with the bark beetles in the killing of Pacific silver fir. Salvage of infested trees was used to control the outbreak.

508. ________
1952. Forest type classification for Pacific Northwest Region.* Pac. NW. Forest & Range Expt. Sta., 33 pp.

509. ________
1953. Density, fiber length, and yields of pulp for various species of wood.* Forest Prod. Lab. Tech. Note 191 (rev.), 9 pp.

The average length of fibers from Pacific silver fir is 3.55 mm. The density of the wood is 24 pounds per cubic foot. Yields of chemical pulps for various processes are: sulfite, 49 percent; sulfate, 49 percent; and soda, 42 percent.

510. ________ 1953. Volume tables for permanent sample plots as recommended by the Puget Sound Research Center Advisory Committee for use in western Washington.* Pac. NW. Forest & Range Expt. Sta., 28 tables.

A compilation of the best existing volume tables applicable to the important commercial trees in the Puget Sound region. Pacific silver fir is included.

511. ________ 1954. Annual report, 1953.* Pac. NW. Forest & Range Expt. Sta., 68 pp.

The silver fir beetle *(Pseudohylesinus* sp.) infestation increased to 603,000 acres, primarily in Washington. Merchantable Pacific silver fir is particularly susceptible. Causes of the outbreak were unknown and control measures were not satisfactory. Salvage of dead and dying timber was in process.

512. ________ 1955. Annual report, 1954.* Pac. NW. Forest & Range Expt. Sta., 68 pp.

In 1954, the silver fir beetle *(Pseudohylesinus* sp.) infestation increased to 652,230 acres in Washington and Oregon. A special survey in the infested area indicated a total Pacific silver fir volume of 6,949 million board feet, of which 528 million board feet was recently killed and 1,332 million was considered high risk. Deterioration studies of the beetle-killed trees indicated Pacific silver fir should be salvaged within 4 years of death. Approximately 147 million board feet of Pacific silver fir was salvaged in 1954.

In 1954, Pacific silver fir was also severely attacked by the balsam woolly aphid *(Chermes piceae)* which infested 146,240 acres along with silver fir beetles and 129,920 acres alone. Most of the Pacific silver fir was dead or dying on heavily infested areas.

513. ________ 1955. Wood handbook. U.S. Dept. Agr. Handb. 72, 528 pp., illus.

514. ________ 1956. Annual report, 1955.* Pac. NW. Forest & Range Expt. Sta., 84 pp., illus.

The silver fir beetle *(Pseudohylesinus* sp.) infestation declined to 114,000 acres in 1955. Biological studies were directed at the life cycle and feeding habits of the insects. These studies showed that the moisture content and degree of deterioration of the tree cambium are important factors in broad development.

Exploratory studies were being continued on the balsam woolly aphid *(Chermes* sp.) which were still killing Pacific silver fir extensively.

515. ________ 1957. Annual report, 1956.* Pac. NW. Forest & Range Expt. Sta., 107 pp., illus.

The *Chermes* infestation was still spreading and killing trees. Crown infestations kill terminal and lateral buds causing trees to die slowly whereas bole infestations cause a more rapid death of the trees.

The silver fir beetle infestation declined to a very low point in 1956. Trap tree and rearing studies provided considerable information about the insects, hymenopterous parasites, insect-attacking fungi, and bacteria which have been collected and identified. *Armillaria mellea* seems to be associated with the beetles.

516. U.S. Forest Service.
1957. Forest resources and forest industries of Lane County, Oregon.* Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 131, 117 pp., illus.

Four true firs (Pacific silver, noble, white, and subalpine firs) and Engelmann spruce had a combined sawtimber volume of nearly 14 billion board feet in the higher elevations of Lane County.

517. ________
1958. Annual report, 1957.* Pac. NW. Forest & Range Expt. Sta., 82 pp., illus.

"The balsam woolly aphid... continued to spread and kill true firs in Oregon and Washington...." Life history studies show the insect may have four generations per year in mild localities although it has only two generations per year in Europe. Almost 2,000 predaceous flies *(Aphidoletes thompsoni)*, imported from Europe, were released at selected localities. Several native predators have been found.

Color photographs at a scale of 1:4,000 can be used successfully to identify the true firs and distinguish those that are dead and those that are heavily damaged.

518. ________
1958. Timber resources for America's future. Separate 13. Appendix--Criteria for rating productivity. Forest Resource Rpt. 14, pp. 670-704.

519. ________
1959. Annual report, 1958.* Pac. NW. Forest & Range Expt. Sta., 94 pp., illus.

Six species of foreign insect predators of the balsam woolly aphid were imported and were being colonized. The life cycles of some native predators are poorly synchronized with that of the aphid and they are effective only with high aphid populations.

A list of 14 species of true fir was included, indicating the degree of damage each species suffers when attacked by balsam woolly aphid.

520. ________
1959. 1959 seed and plant stock dealers. 19 pp.

A directory of American seed suppliers of common forest and shelterbelt plants.

521. U.S. Forest Service.
1960. Annual report, 1959.* Pac. NW. Forest & Range Expt. Sta., 90 pp., illus.

"Findings to date indicate that, among true firs of the Northwest, subalpine fir is by far the most susceptible to attack and damage by the aphid. Pacific silver fir and grand fir are next in susceptibility."

522. ________
1960. Production and marketing of Christmas trees in the Pacific Northwest.* Region 6, 21 pp., illus.

Pacific silver fir, together with noble fir, accounted for 0.6 percent of the Christmas trees produced in Oregon. Pacific silver fir brought about the same prices as Shasta red fir and noble fir, averaging $1 per lineal foot in retail yards. High-elevation true firs, including silver fir, were in greater demand and greater supply. The increase in production of true firs was due to more Christmas tree sales by timber companies, a gradual increase in high-elevation cutover areas, and to an open winter that permitted access to cutting areas well into December.

523. ________
1961. Annual report, 1960.* Pac. NW. Forest & Range Expt. Sta., 97 pp., illus.

Aphid host-tree susceptibility studies indicated that susceptibility increases with tree age for grand fir, and at a given age the fastest growing trees are the most susceptible. It was suggested that this relationship is also true for subalpine fir and Pacific silver fir.

524. ________
1961. Forest insect conditions in the United States, 1960. 38 pp., illus.

525. ________
1962. Annual report, 1961.* Pac. NW. Forest & Range Expt. Sta., 105 pp., illus.

Of the 18 species of insect predators of balsam woolly aphid colonized before 1961, a small beetle, *Laricobius erichsonii*, is probably the most effective. Three species of flies have also become established.

Cooperative studies were being made with Weyerhaeuser Co. to determine the effect of aphid infestation on the growth rate of Pacific silver fir, subalpine fir, and grand fir. In general, stem-infested Pacific silver fir and subalpine fir die within 2 to 4 years after initial attack. However, grand fir can withstand heavy infestations for 12 years or longer although showing serious growth losses, particularly in height.

526. ________
1963. Internationally dangerous forest tree diseases. U.S. Dept. Agr. Misc. Pub. 939, 122 pp.

527. ________
1963. 1963 seed and planting stock dealers. Tree Planters' Notes 60, 25 pp.

A directory of commercial dealers in seeds and planting stock for common trees and shrubs.

528. University of British Columbia.
[n.d.] The first decade of management research--U.B.C. Forest, 1949-1958. Univ. Brit. Columbia, 82 pp., illus.

529. ___________
1961. University of British Columbia Research Forest, Haney, British Columbia, annual report for period April 1, 1960 to March 31, 1961. Faculty of Forestry, 26 pp., illus.

A western hemlock-Pacific silver fir spacing test was established at 3- and 6-foot spacings; lammas shoots were observed on Pacific silver fir (p. 10); data on growth and survival of planted Pacific silver fir are provided on pages 11-13.

530. University of British Columbia Forest Club.
1959. Forestry handbook for British Columbia. Ed. 2, 800 pp., illus. Vancouver, British Columbia: University British Columbia Forest Club.

A compilation of general forestry information in sufficient detail to be very useful. Much information on Pacific silver fir is included.

531. Uphof, J. C. Th.
1920. Die Waldflora im Staate Washington. Vegetationsbilder, 13 Reihe, Heft 7, illus.

A generalized presentation of Washington flora by life zones with six photographs.

532. Usher, Jack H., and Hall, Hoyt H.
1957. Forest statistics for Lincoln County, Oregon.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Forest Survey Rpt. 129, 30 pp., illus.

In 1955, 197 million board feet (Scribner) of Pacific silver fir sawtimber and 35 million cubic feet of growing stock were estimated on commercial forest land in Lincoln County.

533. Van Dersal, William R.
1938. Native woody plants of the United States; their erosion-control and wildlife values. U.S. Dept. Agr. Misc. Pub. 303, 362 pp., illus.

Pacific silver fir: "A very large, long-lived evergreen tree; slow growing; susceptible to fire damage because of its thin bark; somewhat attacked by rot; wood of importance commercially, especially as pulp; grows poorly in cultivation; seeds borne heavily every 2 or 3 years, vitality transient, germination low, 11,000 seeds per pound."

534. Veitch, Harry J.
1892. The Coniferae of Japan. Jour. Roy. Hort. Soc. London 14: 18-33.

"*Abies veitchii*...foliage...may be compared with that of *A. amabilis* and *A. Nordmanniana*, between which it is intermediate in colour, but the leaves are far more silvery beneath than either" (p. 25).

535. Veitch, James.
1900. Veitch's manual of the Coniferae. Revised by Adolphus H. Kent (new ed.), 562 pp., illus. Chelsea, S. W.: James Veitch & Sons, Ltd.

Contains a botanical description and range references of Pacific silver fir and recounts the discovery of the species by David Douglas in September 1825.

536. Viguié, Marié-Thérèse, and Gaussen, Henri.
1928-1929. Révision du genre *Abies*. I. Historique. II. Description du genre. III. Monographie et iconographie des espèces. Toulouse Soc. d'Hist. Nat. Bul. 57: 369-434, illus.; 58: 245-564, illus. (Reprinted as Toulouse Univ. Lab. Forest. Trav., tome 2, v. 2, art. 1, 386 pp., illus. 1928-29.)

The discussion of Pacific silver fir contains a long listing of names and synonyms for the species, a list of arboretums in France where Pacific silver fir is growing (mentions the seed sources), a detailed botanical description, and illustrations.

537. Vité, J. P., and Rudinsky, J. A.
1959. The water-conducting systems in conifers and their importance to the distribution of trunk injected chemicals. Boyce Thompson Inst. Contrib. 20(1): 27-38, illus.

All of the true firs studied, including Pacific silver fir, exhibited a clockwise, spiral, conducting system. The genus was further characterized by a precise arrangement of the tracheidal conduits, an excellent intake of dye, and an ability to transport dye long distances.

538. Wakefield, W. E.
1957. Determination of the strength properties and physical characteristics of Canadian woods. Canada Dept. North. Aff. & Natl. Resources Forestry Branch Bul. 119, 64 pp., illus.

539. Walters, J., and Soos, J.
1962. The vertical and horizontal organization of growth in some conifers of British Columbia. Univ. Brit. Columbia Faculty of Forestry Res. Paper 51, 11 pp., illus.

Includes a stem analysis of a suppressed Pacific silver fir.

540. Warren, H. V., and Delavault, R. E.
1949. Further studies in biogeochemistry. Geol. Soc. Amer. Bul. 60: 531-560, illus.

Includes copper and zinc analyses of Pacific silver fir.

541. __________ Delavault, R. E., and Irish, Ruth I.
1952. Biogeochemical investigations in the Pacific Northwest. Geol. Soc. Amer. Bul. 63: 435-484, illus.

Normal and abnormal amounts of copper and zinc were found in various parts of plants including Pacific silver fir and subalpine fir. The biogeochemical behavior of these species is similar.

542. Warren, H. V., Delavault, R. E., and Fortescue, J. A. C.
1955. Sampling in biogeochemistry. Geol. Soc. Amer. Bul. 66: 229-238, illus.

Includes copper and zinc analyses of Pacific silver fir. Pacific silver fir is useful in prospecting for copper deposits.

543. __________ and Howatson, C. H.
1947. Biogeochemical prospecting for copper and zinc. Geol. Soc. Amer. Bul. 58: 803-820, illus.

Includes copper and zinc analyses of Pacific silver fir twigs and leaves in areas of ore concentrations.

544. Weaver, Harold.
1961. Ecological changes in the ponderosa pine forest of Cedar Valley in southern Washington. Ecology 42: 416-420, illus.

545. Wells, Sidney D., and Rue, John D.
1927. The suitability of American woods for paper pulp. U.S. Dept. Agr. Bul. 1485, 102 pp., illus.

546. West, W. I.
1949. A collection of Oregon woods. Oreg. State Col. School Forestry Cir. 1, 31 pp.

547. Western Forestry and Conservation Association.
1950. Reports of the West Coast Forestry Procedures Committee on various recommended forest practices and techniques. 67 pp. Portland, Oreg.

548. Western Pine Association.
[n.d.] Facts about white fir. 4 pp. Portland, Oreg.

This brochure describes the various properties, uses, and grading of white fir lumber which is manufactured from the following true firs: Pacific silver, white, grand, and California red firs.

549. Weyerhaeuser Company.
[n.d.] 1960 Forestry Research Report. Forestry Res. Center, 20 pp. [unnumbered].

550. Weyerhaeuser Timber Company.
1957. Annual report for 1956. Forestry Res. Center, 39 pp.

Cutting tests of Pacific silver fir seeds revealed a range of filled seed per cone of 6.7 to 35.0 percent. All cones from a given tree contained approximately the same percentage of filled seed.

Trend plots were established in mature Pacific silver fir stands infested by the balsam woolly aphid in 1954 and 1956 to "(1)...determine the rate of tree mortality, stand decline, and timber deterioration resulting from Chermes infestation, and (2) to develop a marking guide based on mortality risk for use in planning salvage." Results to date showed annual basal area losses up to 28 percent and 11,000 board feet per acre. Some trees survived heavy stem infestation by growing a layer of secondary peridem.

The aphid affects trees ranging in size from seedlings to specimens 6 feet in d.b.h. An attempt was made to study the tumor effect of the aphid on transplanted Pacific silver fir seedlings artificially inoculated with the aphid homogenate. No tumors were produced, however.

551. ________ 1958. Annual report for 1957. Forestry Res. Center, 51 pp.

Twenty-one thousand endrin-coated or nontreated seed per acre were broadcast uniformly on a high-elevation burn in 1955. In July 1957, 300 and 900 seedlings per acre remained from the broadcasting of untreated and treated seed, respectively.

A test was begun of the response of planted Douglas-fir, noble fir, Pacific silver fir, and grand fir seedlings to fertilization with four levels each of nitrogen, phosphorus, and potassium. All species, except for Pacific silver fir, varied in their response to different fertilizer levels.

Cones collected at 2-week intervals from Pacific silver fir trees growing at an altitude of 4,500 feet contained no viable seed until September 21. In five cases out of seven, seed from cones which overwintered on the tree in plastic net bags had a higher germination percentage than seed collected on September 27 and stored during the winter at 0° F. and 12-percent seed moisture content.

A small-scale deterioration study of Chermes-killed Pacific silver fir indicated that the quantity of wood loss is correlated with the time since death. For trees dead 1 year, 2 to 3 years, and over 3 years, decay averages 16, 41, and 52 percent of the merchantable cubic volume, respectively. Pulping tests showed a 7-percent volume loss in cleaning and chipping pulp logs produced from trees dead 3 years.

Observations of Chermes infestations on the St. Helens Tree Farm revealed the duration of insect generations on the boles of Pacific silver fir is longer than on grand fir and shorter than on subalpine fir.

Greenhouse-grown 1-year-old Pacific silver and noble firs were inoculated with Chermes to provide information on insect development and gall formation and to provide a means of testing insecticides. "The infestation of trees prior to bud-bursting completely halted growth on the terminal and lateral branches, even though infested by as few as one or two aphids. Abnormal swellings or galls are produced around the buds and at branch nodes and along the main tree stem. Trees infested subsequent to bud bursting were gouted at the nodes and on the stem. After buds were formed on the new growth aphids attacked and also galled them."

Reexamination of trend plots established in a Chermes-infested old-growth Pacific silver fir stand showed a maximum loss of 7,000 board feet per acre (18.7 percent of the total Pacific silver fir volume). The 1956 and 1957 mortality trends on all seven study plots are tabulated. Severe gouting of the branch tips, heavy branch killing, and sparse foliage characterize trees dying over an extended period. These characteristics may not be evident on trees which die in a comparatively short time.

552. ________ 1959. 1958 Forestry Research Report. Forestry Res. Center, 39 pp.

553. Whiteside, J. M.
1957. Forest insect conditions in the Pacific Northwest--1956.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 40 pp., illus.

554. ________
1958. Forest insect conditions in the Pacific Northwest during 1957.* U.S. Forest Serv. Pac. NW. Forest & Range Expt. Sta., 49 pp., illus.

555. Whitford, H. N., and Craig, Roland D.
1918. Forests of British Columbia. Comn. Conserv. Canada, 409 pp., illus. Ottawa.

Describes the geographic, physiographic, and climatic relations and species composition of British Columbia forests. Estimates of the available supply of timber in the province are included and conditions affecting the administration and utilization of the forests are discussed.

556. Wiesehuegel, E. G.
1932. Diagnostic characteristics of the xylem of the North American Abies. Bot. Gaz. 93: 55-70, illus.

Wiesehuegel examined numerous specimens of wood, taken from trees characteristic of the species in many areas within its habitat, to construct an identification key.

Pacific silver fir: "Heartwood and sapwood light brown to buff or light ivory yellow in color but without reddish tinge in springwood; sometimes a reddish tinge in summerwood, transition spring to summerwood gradual.... Resin passages absent in normal wood, or if present are of traumatic character in frost rings or scars...crystals absent in ray parenchyma cells. Resin cells prominent, many partly biseriate rays present, mostly one pit per crossfield, rays up to 62 cells high."

557. Williston, E. M.
1960. Proposed: New stress values for the coast white woods. Forest Prod. Jour. 10: 621-625, illus.

Williston discusses the volume and distribution of the "coast white woods" (western hemlock, Pacific silver fir, grand fir, and noble fir) and by means of tables compares published data on their respective strength properties with new data obtained by Weyerhaeuser Timber Co. The comparison reveals the published stress values are low and are based on an inadequate sample. Until more information is available, Williston suggests that existing western hemlock values be a minimum acceptable level for a grouping of these species to improve their economic utilization.

Pacific silver fir is second only to western hemlock in terms of volume of "coast white woods" with 33.3 billion feet in Washington and 3.7 billion feet in Oregon. Its specific gravity values, based on weight when ovendry and volume when green (presented in table 3), ranged from 0.35 to 0.37.

558. Wilson, Sinclair A.
1929. Key to native trees of Oregon. Pt. 1. Conifers and yews (gymnosperms). 3 pp. [unnumbered]. Compiled in cooperation with Pac. NW. Forest Expt. Sta.

559. Winkenwerder, Hugo, and Wangaard, Frederick F.
1939. Short keys to the native trees of Oregon and Washington. 19 pp. Seattle: Imperial Publishing Co.

560. Wood, R. F.
1955. Studies of north-west American forests in relation to silviculture in Great Britain. Gt. Brit. Forestry Comn. Bul. 25, 42 pp., illus.

Judged by its natural distribution, Pacific silver fir should be more adapted to Britain than grand fir. Introduction trials should be made on the better mountain soils of western Britain.

561. Wright, Ernest, Coulter, W. K., and Gruenfeld, J. J.
1956. Deterioration of beetle-killed Pacific silver fir. Jour. Forestry 54: 322-325.

Presents the results of a study on changes in the physical properties of wood caused by decay fungi that enter beetle-killed Pacific silver fir trees 2 to 4 years after death. Using a technical scale (graphic forms--Forest Service Form 558 A), pathologists estimate that Pacific silver fir trees annually deteriorate 5 percent or more of the total volume up to 4 years after trees are killed.

Three methods were used for log scale cull deductions: a bureau lumber scale (Scribner Decimal C) gave the highest deductions for cull due to rot; a pulp-mill recovery scale (Scribner Decimal C net truck scale) gave the lowest deductions; and the technical scale was intermediate.

The principal rot-causing fungi in decreasing order of importance are: *Fomes pinicola*, brown-cubical rots; *Armillaria mellea*, shoestring rot; *Stereum chaillettii*, patchy rot; and *Polyporus abietinus*, white rot.

562. __________ and Isaac, Leo A.
1956. Decay following logging injury to western hemlock, Sitka spruce, and true firs. U.S. Dept. Agr. Tech. Bul. 1148, 34 pp., illus.

563. Wright, K. H., and Johnson, N. E.
1957. Chermes threaten Northwest white fir forest. Timberman 58(7): 82, 84, illus.

A general account of the balsam woolly aphid outbreak on Pacific silver and subalpine firs in the Washington and Oregon Cascades. The insect's life history and symptoms of its attacks are described.

There is no feasible chemical control but biological control is being attempted by importation of predatory and parasitic insects. Salvage operations are handicapped by inaccessibility of the stricken timber, limited utilization of true firs in the mills, and the checkerboard ownership pattern in the affected areas.

564. Wyman, Donald.
1943. A simple foliage key to the firs. Arnoldia 3: 65-71, illus.

565. Zehetmayr, J. W. L.
1960. Afforestation of upland heaths. Gt. Brit. Forestry Comn. Bul. 32, 145 pp., illus.

Trials of Pacific silver fir are planned to determine its possible use in exposed areas.

566. Zeller, S. M., and Goodding, L. N.
1930. Some species of Atropellis and Scleroderris on conifers in the Pacific Northwest. Phytopathology 20: 555-567, illus.

Scleroderris abieticola Zeller & Goodding, sp. nov., is the name proposed by the authors for a canker-causing fungus found attacking Pacific silver and grand firs. The development of the canker is much slower on Pacific silver fir. The canker and fungus are described and the distribution of the examined specimens is presented.

567. Ziller, W. G.
1959. Studies of western tree rusts. IV. *Uredinopsis hashiokai* and *U. pteridis* causing perennial needle rust of fir. Canad. Jour. Bot. 37: 93-107.

Field observations and inoculation experiments show that the perennial needle rust of firs (including Pacific silver fir) known as *Peridermium pseudo-balsameum* is caused by the pycnial and aecial stages of *Uredinopsis hashiokai* and *U. pteridis*. The taxonomy of the various stages of these two organisms and their life histories are described. Inoculations of Pacific silver fir with *U. hashiokai* were unsuccessful whereas those with *U. pteridis* were successful.

568. __________
1959. Studies of western tree rusts. V. The rusts of hemlock and fir caused by *Melampsora epitea*. Canad. Jour. Bot. 37: 109-119, illus.

569. __________ and Molnar, A. C.
1953. Forest disease survey, British Columbia. Canad. Dept. Agr. Forest Insect & Disease Survey Ann. Rpt. 1952: 142-154.

The distribution of Indian paint fungus *(Echinodontium tinctorium)* on western hemlock and Pacific silver fir in some localities studied is compared in a table.

570. Ziller, Wolf G., and Stirling, David.
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COMMON AND SCIENTIFIC NAMES OF TREE SPECIES NAMED IN CITED LITERATURE

Abies alba	European silver fir
Abies amabilis (Dougl.) Forbes	Pacific silver fir
Abies concolor (Gord. & Glend.) Lindl.	white fir
Abies grandis (Dougl.) Lindl.	grand fir
Abies lasiocarpa (Hook.) Nutt.	subalpine fir
Abies magnifica A. Murr.	California red fir
Abies procera Rehd.	noble fir
Cedrus atlantica	atlas cedar
Chamaecyparis lawsoniana (A. Murr.) Parl.	Port-Orford-cedar
Chamaecyparis nootkatensis (D. Don) Spach	Alaska-cedar
Ginkgo biloba	Ginkgo
Larix occidentalis Nutt.	western larch
Picea engelmannii Parry	Engelmann spruce
Picea sitchensis (Bong.) Carr.	Sitka spruce
Pinus contorta Cougl.	lodgepole pine
Pinus monticola Dougl.	western white pine
Pseudotsuga menziesii (Mirb.) Franco	Douglas-fir
Taxus brevifolia Nutt.	Pacific yew
Thuja plicata Donn	western redcedar
Tsuga heterophylla (Raf.) Sarg.	western hemlock
Tsuga mertensiana (Bong.) Carr.	mountain hemlock

TENTATIVE ECOLOGICAL PROVINCES *within the*

TRUE FIR-HEMLOCK forest areas of the PACIFIC NORTHWEST

by Jerry F. Franklin

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RESEARCH PAPER PNW 22
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Introduction

True fir-hemlock forests occupy extensive areas at middle to high elevations in mountainous regions of Oregon and Washington. These forests are characterized by Pacific silver fir *(Abies amabilis)*, noble fir *(Abies procera)*, Shasta red fir *(Abies magnifica* var. *shastensis)*, subalpine fir *(Abies lasiocarpa)*, western hemlock *(Tsuga heterophylla)*, mountain hemlock *(Tsuga mertensiana)*, and western white pine *(Pinus monticola)*. True fir-hemlock forests constitute a major forest resource, covering approximately 3 million acres and containing about 100 billion board feet of timber. They occupy the upper reaches of many major drainages, occur within summer ranges of big-game animals, and in many areas receive heavy recreational use. Multiple resource aspects of the true fir-hemlock forests are important enough that an appreciable proportion of the area they occupy has been designated "High Mountain Area" (U.S. Forest Service 1962)[1] for which special objectives and policies have been determined.

True fir-hemlock forests are very diverse in character.[2] They occur on mountain habitats covering 7° of latitude and representing widely divergent geologic histories, climatic conditions, and topography. The forests themselves vary a great deal in species composition and stand characteristics and will require a variety of silvicultural prescriptions for intensive management. Thus, we need to subdivide the true fir-hemlock forest areas into as homogeneous and ecologically consistent units as present knowledge permits for purposes of both management and research.

This paper suggests useful geographic divisions of the true fir-hemlock forests within the mountainous regions of western Oregon and Washington. Divisions are based on differences in geology, topography, soil parent materials, climate, and forest composition. Because the regions or provinces are based on a consideration of several factors rather than just a single factor such as physiography or climate, they are considered ecological provinces. The provinces provide a geographic framework which, by reducing the variability of forests and habitats encountered within the true fir-hemlock zones, facilitates isolation and solution of management problems and provides an initial stratification for research purposes.

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[1] Names and dates in parentheses refer to Literature Cited, p. 30.

[2] Excluded from consideration in this paper are the grand fir *(Abies grandis)* forests, common on the eastern slope of the Cascade Range, and the extensive low-elevation western hemlock stands found on the western slopes in which a true fir is not a major constituent.

It is important to recognize that this is a broad, generalized classification of the true fir-hemlock forest area. Within each province, these forests occupy a spectrum of habitats resulting from different environmental conditions--soil types, topographic position, microclimate, etc.--and these habitats are typified by different forest types, understory plant communities and management considerations. In the author's opinion, the classification presented in this report is as detailed as presently possible. As increased information on vegetation (plant communities) and soils and their distribution become available, it will be feasible to develop an ecologic classification of the true fir-hemlock landscape based on individual habitat types which would have essentially identical biologic potential for management.

The province classification provided in this paper applies only to areas or elevation zones in which the climax forests are composed of true firs and hemlocks, except as noted in footnote 2. Significant ecological or geographical divisions of adjacent lower elevation forest types or zones may or may not be correlated with this subdivision of the true fir-hemlock forests.

The Provinces

The 11 tentative ecological provinces of the true fir-hemlock forests are:

Mount Baker	Three Sisters
Wenatchee	Crater Lake
Mount Rainier	Olympic
Mount Adams	Coast Range
Willamette	Siskiyou
Mount Hood	

Approximate boundaries of the provinces are illustrated in figure 1, page 17. Data collected throughout the geographic range of true fir-hemlock forests and available literature are the basis of the division into these provinces.

Geologic, topographic, climatic, edaphic, and vegetational characteristics of the various provinces are considered in following sections. Some characteristics are summarized in table 1.

GEOLOGY AND PHYSIOGRAPHY

Geology, and its expression in physiography, provides a good place to begin an ecologic stratification of our northwestern mountainous regions. The 11 ecological provinces occur within 6 areas of gross geologic uniformity[3] (fig. 2, table 1): Northern Cascades, Western Cascades, High Cascades, Olympic Mountains, Coast Ranges, and Siskiyou Mountains. Three of these units are parts of the Cascade Range which have previously been recognized as being biologically distinct (Campbell 1962, Molenaar 1956, Williams 1962). The other three, the Olympic Mountains, Coast Ranges (including the Willapa Hills), and the Siskiyou Mountains, will be considered, for our purposes, as single geologic units.

---

[3] Boundaries of provinces and geologic units do not necessarily coincide, however, because of the other factors (vegetation, soils, and climate) used in determining province boundaries. For example, the Wenatchee Province includes portions of both the Northern Cascades and Western Cascades geologic units because topographic, vegetational, and climatic similarities override differences in bedrock geology. Likewise, the Willamette Province (located mainly in the Western Cascades) includes a portion of the High Cascades geologic unit, and the Crater Lake Province (located mainly in the High Cascades) includes some of the Western Cascades geologic unit. Therefore, the 11 provinces are not simply a subdivision of the 6 geologic units as might be supposed.

Table 1.--Major environmental factors and extent of true fir-hemlock forests in the 11 ecological provin

Ecologic province	Geologic unit	Topography
Mount Baker	Northern Cascades	Extremely rugged; deeply dissected
Mount Rainier	Western Cascades	Dissected, mature ridge and valley topography
Willamette	Western Cascades (mainly)	Dissected, mature ridge and valley topography
Mount Adams	High Cascades	Gentle, rolling
Mount Hood	High Cascades	Gentle, rolling
Three Sisters	High Cascades	Gentle, rolling
Crater Lake	High Cascades (mainly)	Gentle, rolling
Wenatchee	Northern Cascades and Western Cascades	Extremely rugged; deeply dissected
Olympic	Olympic Mountains	Rugged, complex systems of ridges and valleys
Coast Range	Coast Ranges	Mature ridge and valley topography
Siskiyou	Siskiyou Mountains	Rugged, complex systems of ridges and valleys

---

[1] Two aspects of parent materials are considered: (1) mode of origin, e.g., colluvial, residual; (2) parent rock, the material from which soil particles were developed, e.g., sedimentary. Residual parent materials originate by rock disintegration in place; they have not been transported. The other types of parent materials have been transported from other areas to their present location: colluvial, by gravity; alluvial, by water; and glacial (till), by glaciers.

Climate	Major soil parent materials[1]	Extent and continuity of true fir-hemlock forests
ool, moist growing season; little or no summer drought	Colluvial, residual, alluvial, and glacial materials from metamorphic, igneous intrusive, and sedimentary rocks; local volcanic ejecta	Extensive, contiguous stands
	Colluvial, residual, and glacial materials from igneous extrusive rocks; volcanic ejecta as deposits or mixed with other materials	Extensive, insular stands
creasing growing-season temperatures; summer drought	Colluvial, residual, and glacial materials from igneous extrusive rocks; volcanic ejecta as deposits or mixed with other materials	Extensive, insular stands
ecreasing annual and growing-season precipitation	Volcanic ejecta often over residual and glacial igneous extrusive materials	Extensive, contiguous stands
	Glacial, colluvial, and residual materials from igneous extrusive rocks	Extensive, contiguous stands
↓	Volcanic ejecta often over glacial, residual, and colluvial materials from igneous extrusive rocks	Extensive, contiguous stands
arm, dry growing season; marked summer drought period	Volcanic ejecta often over glacial, residual, and colluvial materials from igneous extrusive rocks	Extensive, contiguous stands
arm, dry growing season; marked summer drought period	Colluvial, residual, alluvial, and glacial materials from igneous intrusive or extrusive and metamorphic rocks; local volcanic ejecta	Limited, insular stands
ool, moist growing season; no summer drought	Colluvial, alluvial, residual, and glacial materials from igneous extrusive, sedimentary, and metamorphic rocks	Extensive, contiguous stands
ool, moist growing season; no summer drought	Residual and colluvial materials from igneous intrusive or sedimentary rocks	Extremely limited, insular stands
arm, dry growing season; marked summer drought period	Colluvial and residual materials from igneous intrusive, sedimentary, and metamorphic rocks	Limited, insular stands

Examples of the five categories of parent rock are: (1) igneous intrusive--granite, diorite, gabbro, peridotite; (2) igneous extrusive--andesite, basalt, pyroclastic rocks (e.g., tuffs and volcanic breccias); (3) sedimentary--sandstone, graywacke, shale; (4) metamorphic--gneiss, schist, slate; and (5) volcanic ejecta--defined in this paper as unconsolidated pyroclastic rock fragments, e.g., pumice, ash, lapilli, and cinders.

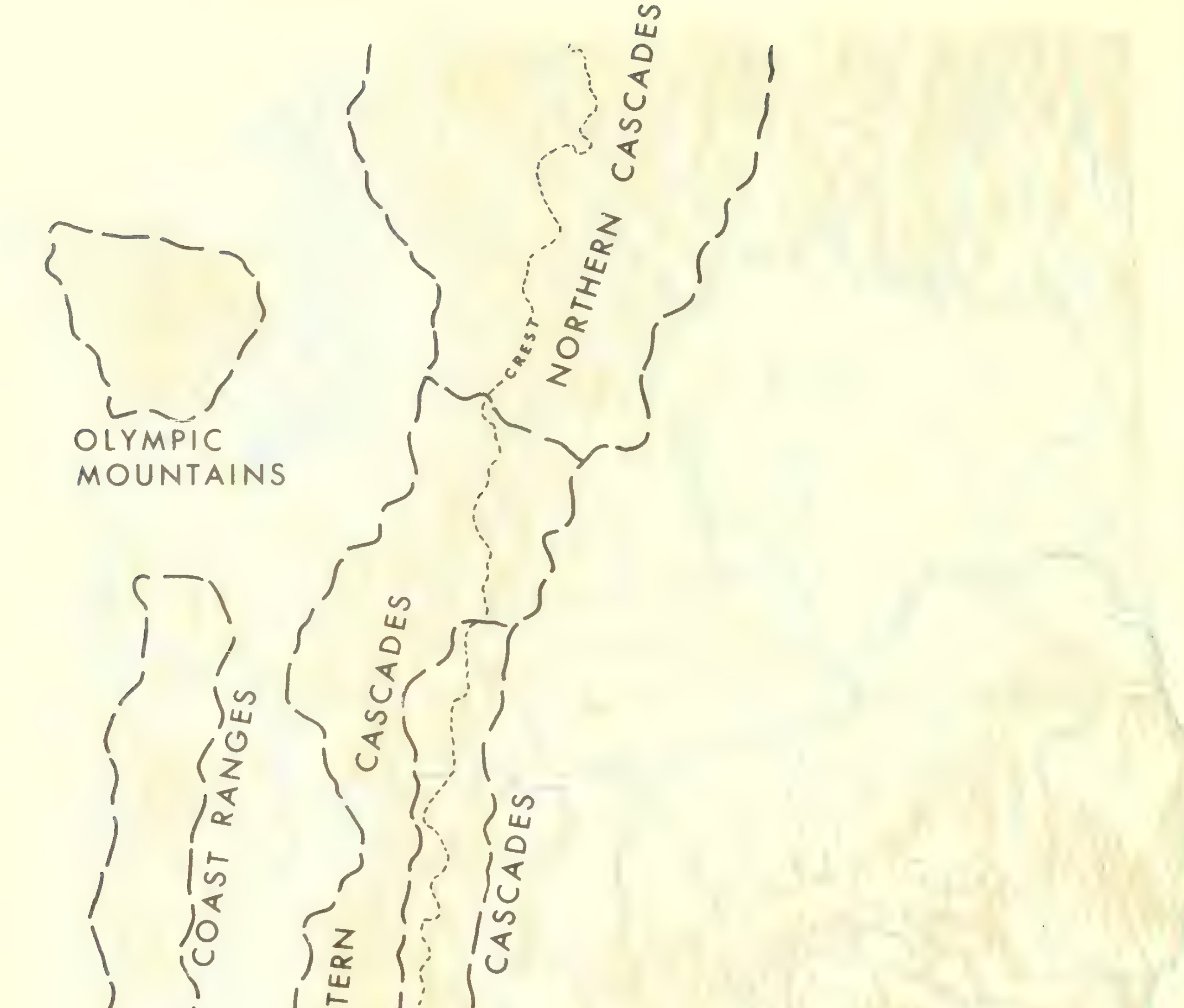


Figure 2 - The six broad, geologic and physiographic units of the Cascade Range and coastal mountain ranges utilized in developing the province classification.

North of Snoqualmie Pass (U.S. Highway 10) is the Northern Cascades, a complex geologic unit dating from the pre-upper Jurassic period (Molenaar 1956). This region is composed mainly of metamorphic, sedimentary, and intrusive igneous rock types. Extrusive igneous rock types are not extensive compared with other parts of the Cascade Range, although Mount Baker and Glacier Peak provide two major "islands" of volcanic materials. The Northern Cascades was the most heavily glaciated part of the range and during the ice age probably looked similar to heavily glaciated parts of Alaska today.

Much of the present Cascade Range was created by an upwarping in late-Tertiary time, but uplift was strongest in the Northern Cascades and decreased steadily to the south. Elevations of higher peaks and ridges are, therefore, greatest in this part of the Cascade Range--7,000 to 8,000 feet. The greater elevation and glaciation of the Northern Cascades are largely responsible for the present rugged topography. Matterhorn-like summits, jagged ridges, glacially carved valleys, and steep-walled cirques contrast with gentler topography in the remainder of the range (fig. 3).

The other two geologic units of the Cascade Range are composed almost entirely of volcanic materials--andesitic, basaltic, and pyroclastic rocks. Williams (1962) described major differences between the Western Cascades and the High Cascades in Oregon, where they lie parallel:

> The Cascade Range is divisible lengthwise into two belts, the Western and the High Cascades. The former consists of the tremendous volcanic accumulations of Eocene, Oligocene, and Miocene times. In this belt profound canyons are separated by narrow ridges, and no trace remains of the original volcanic landscapes. The landforms here are entirely the result of erosion. The High Cascades, on the other hand, are made up of Pliocene and younger volcanic cones whose original forms, even though modified by erosion, are easy to recognize.

Thus, the Western Cascades includes most of the range in Washington south of the Snoqualmie Pass (except for an area around Mount Adams and islands of more recent volcanic materials around Mount St. Helens and Mount Rainier) and the western flank of the range in Oregon. In Washington and northern Oregon, the dominant rock types are andesite and basalt, whereas, in the southern Oregon portion of the Western Cascades, pyroclastic rocks are the predominant type.

Most of the Western Cascades presents a mature ridge and valley topography which is rugged but generally not so precipitous as that typically found in the Northern Cascades (fig. 4). High-elevation tracts tend to be insular and limited in extent. In contrast, the larger volcanic cones of this geologic unit--Mount Rainier and Mount St. Helens--rise far above the generally concordant level of the numerous smaller peaks and ridges. One part of the Western Cascades is included within the Wenatchee Province because, among other reasons, the topography there is more similar to that found on the eastern slopes of the Northern Cascades.

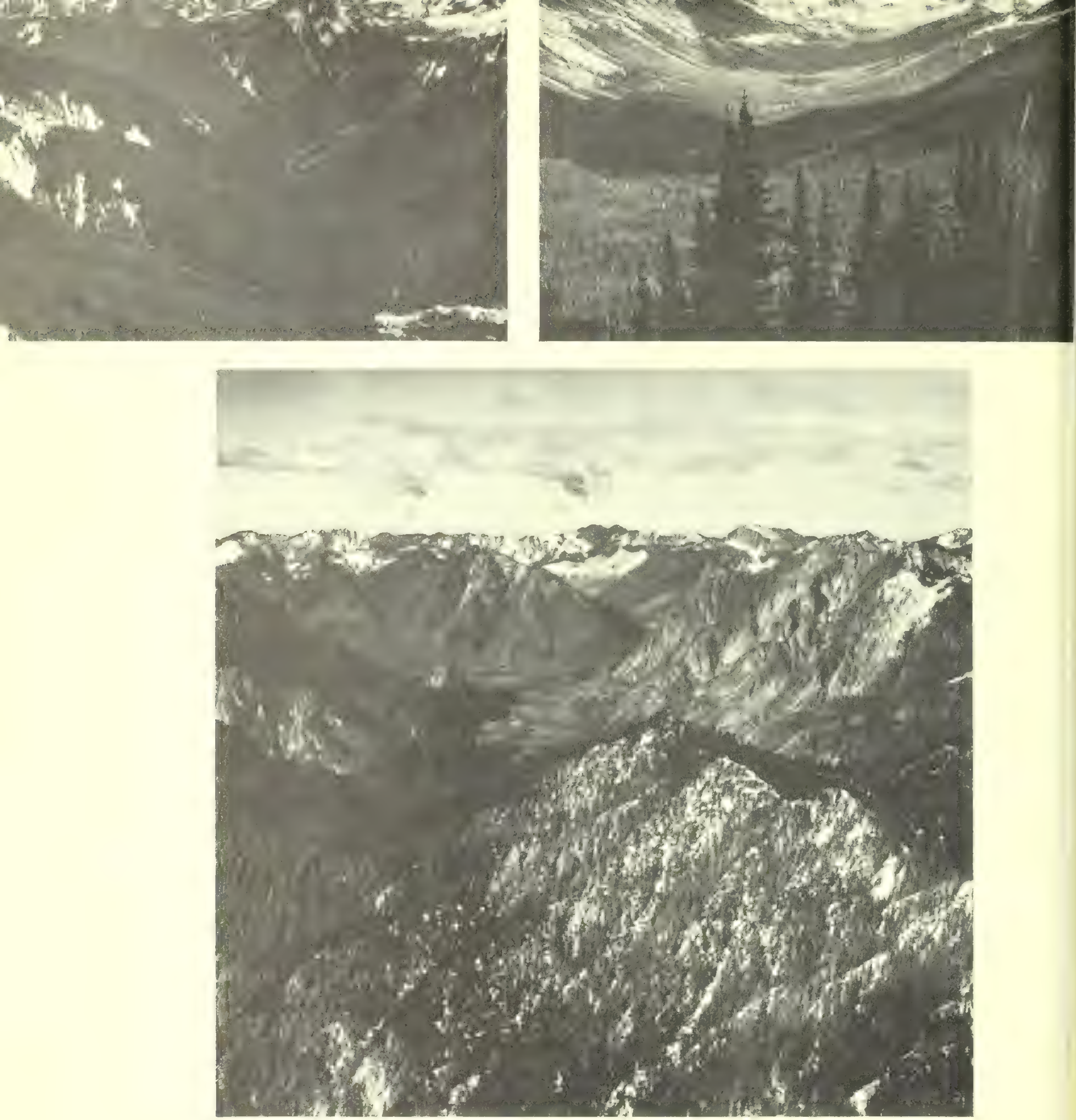
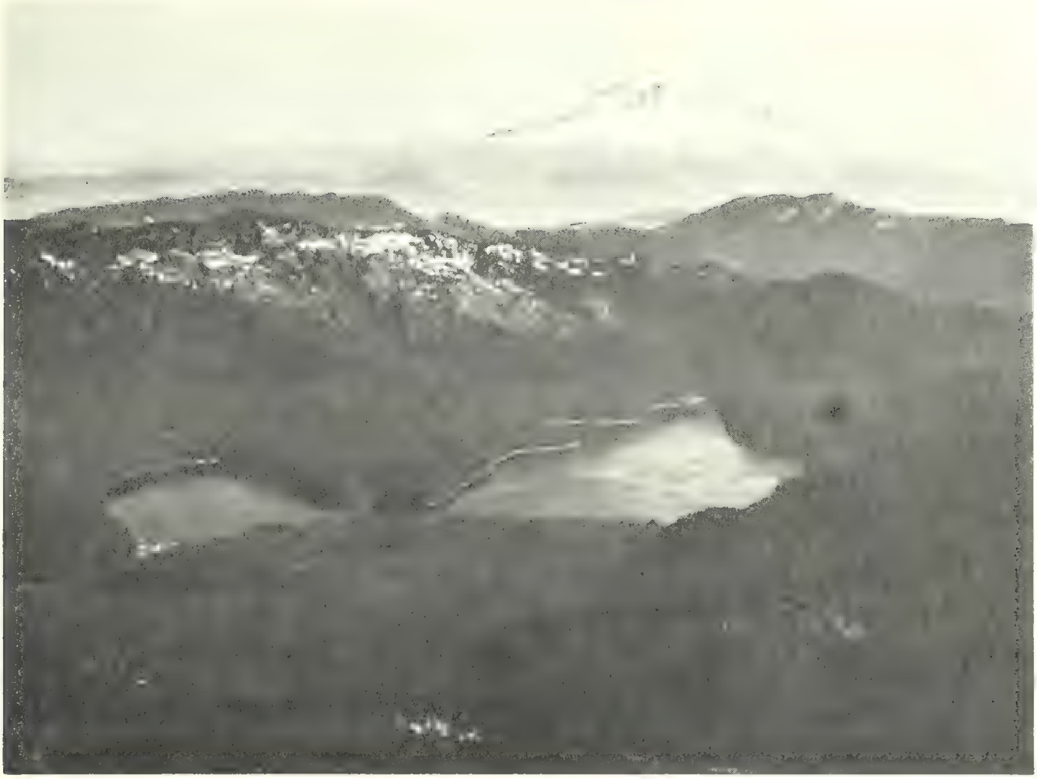


Figure 3.--Typical topographic conditions encountered in the Northern Cascades. Upper left: Chilliwack Creek drainage and Picket Range, Mount Baker National Forest. Upper right: upper Pasayten River drainage from Jim Peak, Okanogan National Forest. Bottom: view down Middle Fork of Snoqualmie River, Snoqualmie National Forest.



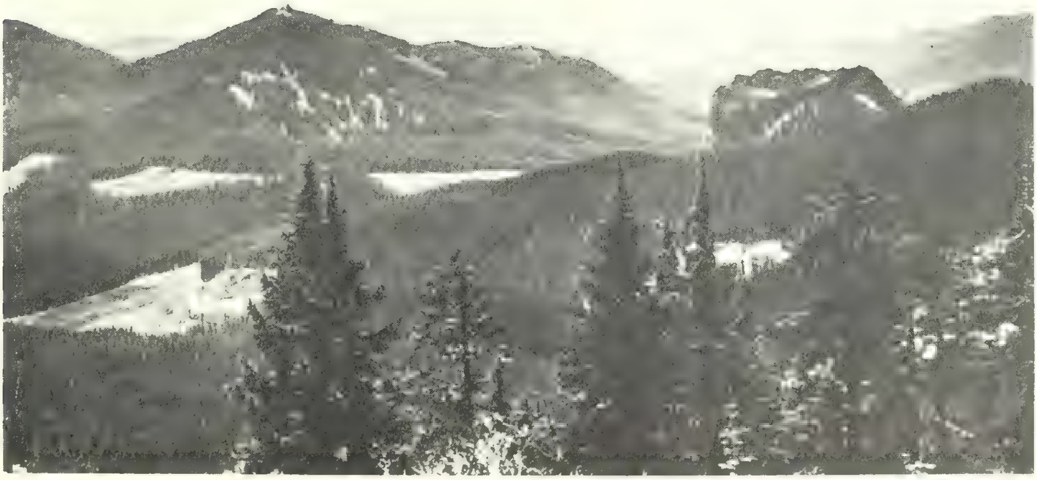


Figure 4.--Typical topographic conditions encountered in the Western Cascades. Top: north of Mount St. Helens, Gifford Pinchot National Forest. Bottom: near Carpenter Mountain and Wolf Rock, Willamette National Forest.

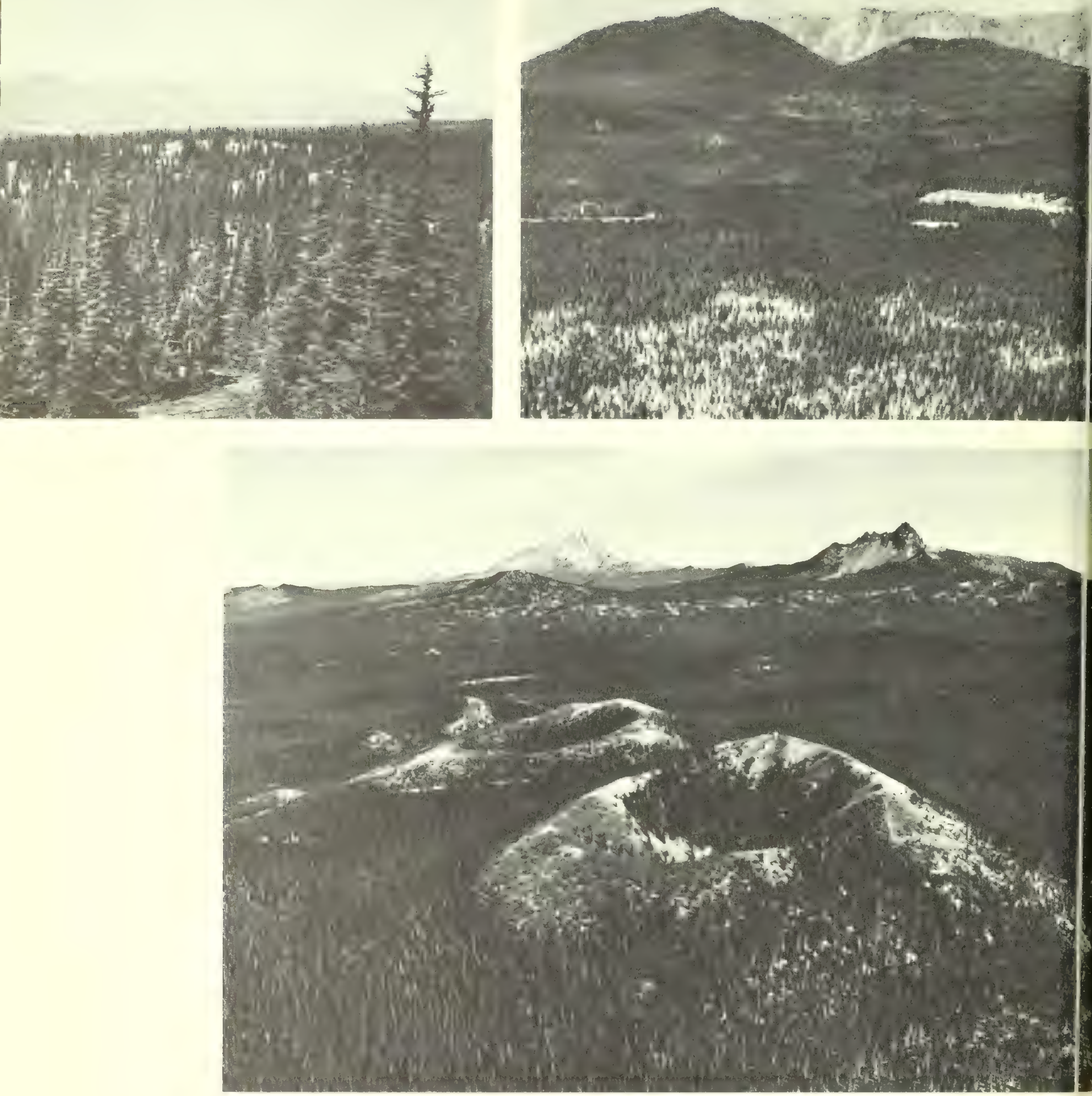


Figure 5.--Typical topographic conditions encountered in the High Cascades. Upper left and bottom: vicinity of Santiam Pass and Mount Washington, Willamette National Forest. Note the rolling topography broken by isolated volcanic peaks and cinder cones. Upper right: west of Mount Adams, Gifford Pinchot National Forest. Notice the mature ridge and valley topography of the Western Cascades in the distance.

The High Cascades is much younger than the Western Cascades and occupies the crest of the Cascade Range throughout the length of Oregon and an area around Mount Adams in southern Washington. Topography here is that of a gently rolling or sloping plateau with poorly defined drainage patterns and a minimum of precipitous topography (fig. 5). Isolated cinder cones and other volcanic landforms provide much of the relief, although glaciation has carved deep canyons in some areas and affected the major peaks. Surface deposits of pumice and other volcanic ejecta cover the bulk of the landscape and many (particularly in the Mount Adams and Crater Lake Provinces) have been subjected to little reworking since deposition. The crest of the High Cascades varies from 4,000 to 6,000 feet in elevation, and high-elevation tracts are, therefore, very extensive and contiguous.

The Olympic and Siskiyou Mountains are rugged mountain systems with complex patterns of valleys and canyons separating high peaks and ridges. The Olympic Mountains are composed mainly of metamorphic, extrusive igneous, and sedimentary rock types. They have been heavily glaciated. The Siskiyou Mountains are composed of metamorphic and intrusive igneous rock types. The Coast Ranges are relatively low mountains with a mature ridge and valley topography and few areas of sufficient elevation to support true fir-hemlock forests. Sedimentary rock types are most common, although higher peaks and ridges are often volcanic or metavolcanic in composition.

CLIMATE

Climatic variation in the Cascade Range is important in the delineation of ecological provinces (table 2). Some general features of the climate throughout the Cascade Range and coastal ranges are well known (U.S. Weather Bureau 1960a, 1960b). Annual precipitation normally increases with elevation of western mountain slopes and decreases rapidly on eastern leeward slopes. Precipitation is markedly seasonal, less than 10 percent of which usually falls from late June to September. At high elevations, much of the precipitation falls as snow and accumulates in winter snowpacks. The maritime climate is mild with cooler summers and warmer winters than at comparable elevations on inland ranges (continental climates).

Some broad variations in the general climatic pattern just described must be considered in a division of true fir-hemlock forest areas (table 2). Southward along western slopes of the Cascade Range, summers become progressively warmer and drier, a summer drought period develops, and total precipitation decreases at a given elevation. This change in climatic pattern necessitates subdividing the Western Cascades latitudinally into the Mount Rainier and Willamette Provinces to provide a greater measure of climatic homogeneity.

Table 2.--Climatic data from some representative stations in the Cascade Range and coastal mountains[1]

Ecological province and weather station	Elevation	In true fir-hemlock zone?	Precipitation: Total annual	Precipitation: June, July & Aug.	Precipitation: Annual snowfall	Temperature: Ave. annual	Temperature: Mean monthly Jan.	Temperature: Mean monthly July	Temperature: Ave. Jan. min.	Temperature: Ave. July max.
	Feet		Inches			Degrees F.				
Mount Baker:										
Mount Baker Lodge	4,150	Yes	111.08	12.32	550.3	40.1	27.3	53.8	21.8	63.5
Stevens Pass	4,085	Yes	65.79	5.10	354.1	39.9	22.8	57.9	16.9	71.1
Scenic	2,224	Yes	77.60	5.50	241.9	--	--	--	--	-
Snoqualmie Pass	3,020	Yes	104.57	8.94	386.5	41.9	26.3	58.0	20.1	70.0
Mount Rainier:										
Stampede Pass	3,958	Yes	93.60	7.34	473.4	46.8	23.7	56.9	19.8	67.2
Parkway	2,640	Yes	54.93	4.35	135.9	44.8	30.3	59.8	25.1	73.7
Mount Rainier, Longmire	2,762	Yes	79.44	6.37	179.4	45.2	30.0	61.1	23.6	74.9
Mount Rainier, Paradise	5,550	Yes	101.49	9.08	536.4	38.5	26.3	53.1	20.1	62.8
Spirit Lake R.S.	3,240	Yes	88.69	5.52	282.6	42.0	28.4	58.8	24.1	72.2
Willamette:										
Summit G.S.	3,900	Yes	84.09	7.12	301.5	42.2	29.0	57.8	22.0	72.4
Sundown Ranch	2,400	No	74.67	5.49	93.6	47.8	35.9	60.1	30.0	71.6
Oakridge R.S.	1,310	No	42.32	3.00	14.5	53.2	38.1	68.0	30.0	84.9
Detroit	1,730	No	74.22	3.25	67.1	48.5	33.0	63.5	25.3	81.2
McKenzie Bridge R.S.	1,375	No	68.93	4.23	39.8	50.5	34.5	66.8	27.3	85.1
Wenatchee:										
Blewett Pass	4,071	Yes	28.07	2.37	186.5	43.6	24.4	64.0	19.1	77.6
Holden	3,436	Yes	34.74	2.57	290.0	42.6	20.4	62.2	14.4	75.4
Chiwawa River	2,712	--	62.42	3.08	364.0	--	--	--	--	--
Lake Wenatchee	1,970	No	39.67	2.29	170.3	--	--	--	--	--
Bumping Lake	3,440	Yes	45.92	2.65	219.0	40.3	22.4	58.0	11.7	74.1
Lake Kachess	2,270	Yes	54.80	3.16	159.3	44.7	25.3	63.7	18.2	77.8
Mount Adams:										
Mount Adams R.S.	1,960	No	48.21	1.91	118.5	46.7	28.1	65.3	20.8	83.3
Mount Hood:										
Parkdale	1,740	No	45.11	1.91	95.9	47.3	29.8	63.5	22.3	80.6
Three Sisters:										
Odell Lake Land Pan	4,788	Yes	59.30	2.33	--	40.4	23.2	58.5	15.5	74.6
Wickiup Dam	4,330	No	20.08	2.53	78.4	41.2	21.8	59.6	7.9	80.0
Crater Lake:										
Crater Lake NPS Hq.	6,475	Yes	68.46	3.95	589.3	39.3	25.2	56.4	17.0	70.4
Cascade Summit	4,841	--	49.63	3.00	294.9	41.5	26.9	58.8	20.0	80.9
Fish Lake	4,687	--	45.47	2.97	171.7	44.1	28.4	61.1	18.9	78.0
Siskiyou:										
Siskiyou Summit[2]	4,480	No	22.70	1.74	104.4	46.8	31.8	64.0	25.4	75.6
Illahe 1 N[3]	300	No	85.79	2.64	14.9	55.1	40.2	70.4	34.6	79.7
Coast Range:										
Corvallis Water Bureau[2]	450	No	70.12	2.50	19.6	—	--	—	--	--
Valsetz[3]	1,150	No	124.02	5.80	15.5	50.1	37.2	62.2	29.8	77.4
Olympic:										
Forks[3]	350	No	115.87	8.35	15.0	49.2	38.5	59.7	32.6	70.3
Spruce[3]	410	No	123.80	9.80	20.5	--	--	--	--	--
Quilcene 2 SW[2]	123	No	48.10	4.04	6.2	50.3	36.7	63.5	29.3	77.4

[1] From U.S. Weather Bureau records for 1931 through 1952 (U.S. Weather Bureau 1956a, 1956b).

[2] East (inland) side of range.

[3] West (ocean) side of range.

Eastward from the crest of the Cascade Range in northern and central Washington, annual precipitation decreases (even at high elevation), summers become warmer and drier, and winter temperatures become colder (U.S. Weather Bureau 1960b). These differences in precipitation and temperature provide a climatic basis for separating the Wenatchee Province from the adjacent, geologically related, west slope areas.

The four High Cascades provinces (Mount Adams, Mount Hood, Three Sisters, and Crater Lake) straddle the crest of the Cascade Range. Summers are warmer and winters are cooler, and the climate is, in general, more continental than in adjacent provinces located in the Western Cascades. Both annual precipitation and that which occurs during the growing season are usually less at comparable elevations (U.S. Weather Bureau 1960a). Furthermore, there is a gradual decrease in precipitation and an increase in summer temperatures from north to south through the High Cascades, necessitating the division of this geologic unit because of climatic variation. Actual boundaries of the four provinces were determined by details of soil parent materials and vegetation because of the gradational change in climate.

Superimposed on this broader pattern of climatic variation are many localized macroclimatic variations within individual provinces. Localized effects of this type sometimes obscure the larger scale geographical shifts in macroclimate.

SOILS

Variation in soil parent material in the various provinces is closely related to the geologic regions. In the Northern Cascades, for example, colluvium, alluvium, and glacial till derived from sedimentary, metamorphic, and igneous intrusive rock types are the important parent materials except near Mount Baker and Glacier Peak where some deposits of volcanic ash and pumice are present.

In the Western Cascades, colluvial and residual parent materials derived from andesitic, basaltic, and pyroclastic rock types are most important, but they are often mixed with volcanic ejecta. In the vicinity of Mount Rainier and Mount St. Helens, soils may be developed entirely in deposits of pumice and lapilli.

In the High Cascades, the majority of soils are developed in recent surface deposits of volcanic ash, pumice, cinders, lapilli, and other unconsolidated pyroclastic materials, overlying either basic igneous rocks or buried profiles developed from these rocks. Over much of the area, particularly in the Mount Adams and Crater Lake Provinces, the most recent deposits have not been reworked by erosional processes and the various layers are readily apparent. Deposits of ejecta have been reworked, primarily by glaciation, around some major peaks. The Mount Hood Province provides a single large-scale exception where unconsolidated deposits of unreworked volcanic ejecta do not constitute a major soil parent material in this province. Most soils in the Mount Hood Province are developed in residuum and colluvium derived from andesite and basalt and in glacial till of varying composition.

Parent materials in the Olympic Mountains are usually residuum, colluvium, and glacial till derived from metamorphic, sedimentary, and igneous extrusive (e.g., basalt) rock types. The Siskiyou Mountains contain an even wider spectrum of parent rock types, and parent materials are mainly residual or colluvial in origin. Soils in the Coast Ranges are generally developed in sedimentary or igneous extrusive residuum or colluvium.

Great soil groups commonly found in true fir-hemlock forests are Podzols, Brown Podzolics, Regosols, Lithosols, Sol Brun Acides, and Yellowish-Brown Lateritics.[4] In the Cascade Range, Podzols attain maximum development at midelevations on western slopes of the Northern Cascades. Organic horizons sometimes attain thicknesses of 14 inches and A2 horizons may be 3 inches thick under Pacific silver fir-western hemlock stands. Podzols are the soil type found most often under true fir-hemlock stands regardless of the province. Degree of podzolization varies a great deal, however, decreasing from north to south and as one moves down the eastern slopes of the Cascade Range. Near the southern end of the Oregon Cascades and along eastern boundaries of the true fir-hemlock forests, podzolization is at a minimum, and zonal soils probably become Brown Podzolics except at the highest elevations.

It is important to note that many of the grey, ashy A2 horizons commonly encountered in podzolic profiles in the Washington Cascade Range are not primarily the result of podzolization, i.e., soil development in place. On the contrary, these horizons appear to have originated as recent depositions of volcanic ash and pumice, particularly by Mount St. Helens and Glacier Peak (Crandell et al. 1962; Carithers 1946). These pyroclastic materials had many of the characteristics of a podzolic A2 at the time of deposition (e.g., coarse texture, grey or white color, position in solum) and have since acquired additional features characteristic of A2 horizons (e.g., increase in acidity).

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[4] The U.S. Department of Agriculture (1938) and Thorp and Smith (1949) define the first four great soil groups as follows: **Podzol** soils have an organic mat (usually mor or raw humus consisting of matted and compacted unincorporated organic matter) and very thin, organic-mineral layer above a gray leached layer (A2) which rests upon an illuvial dark-brown horizon (B2). Iron oxide, alumina, and colloidal organic matter have been removed from the A and deposited in the B horizon. **Brown Podzolic** soils have a thin mat of partly decayed organic matter over very thin, dark grayish-brown, humus-mineral soil and a trace of pale-gray, leached A2 horizon over a brown or yellowish-brown B horizon heavier in texture than the surface soil. **Regosols** consist of deep, unconsolidated rock (loess, sand, pumice, e.g.) in which few or no clearly expressed soil characteristics have developed. **Lithosols** are skeletal soils consisting of a fresh and imperfectly weathered mass of rock fragments which have no clearly expressed soil morphology. As recognized by soil scientists in the Pacific Northwest, Podzols generally lack the thin, organic-mineral layer above the A2, and Brown Podzolics have thin to thick mats of organic matter and often lack textural B horizons.

Sol Brun Acides and Yellowish-Brown Lateritics are reported to occur under true fir-hemlock stands (in a personal communication from Freeman Stephens and Jack S. Fisher, soil scientists, Region 6, U.S. Forest Service). **Sol Brun Acides** are deep, moderately to poorly weathered soils with indistinct horizons and containing primary minerals besides quartz (Harris 1963). **Yellowish-Brown Lateritics** have yellowish-brown, granular, friable surface horizons overlying yellow or reddish-yellow friable clay material and rest on parent materials usually not strongly mottled (U.S. Department of Agriculture 1938).

FORESTS

The climax species in the true fir-hemlock zones under consideration are true firs and hemlocks, but the exact composition, especially of seral species, varies considerably from province to province. This variability is important in dividing these mountain areas into provinces. The relative importance of the species is shown in table 3. All forest types occurring in the true fir-hemlock zones[5] are being considered, regardless of successional status or species composition.

Table 3.--Forest composition in the true fir-hemlock zones, by ecological provinces [1]

	Province										
Species	Mount Baker	Mount Rainier	Willamette	Mount Adams	Mount Hood	Three Sisters	Crater Lake	Wenatchee	Olympic	Coast Range	Siskiyou
Pacific silver fir	M	M	M	M	M	M	m	m	M	m	-
Noble fir	m	M	M	M	M	m	m	m	--	m	m
Shasta red fir	--	--	--	--	--	--	M[2]	--	--	--	M[2]
Western hemlock	M	M	M	M	M	M	m	m	M	M	--
Mountain hemlock	M	M	m	M	M	M	M	m	M	--	M
Western white pine	m	m	m	M	M	M	M	M	m	--	M
Douglas-fir	M	M	M	M	m	m	m	m	M	M	--
Western redcedar	M	M	m	m	m	--	--	m	M	m	--
Alaska-cedar	m	m	m	m	m	--	--	--	m	--	--
Lodgepole pine	m	m	m	M	M	M	M	M	--	--	m
Engelmann spruce	--	m	m	M	M	m	m	M	--	--	--
Subalpine fir	m	m	m	M	M	M	m	M	m	--	--
Western larch	--	--	--	M	M	--	--	M	--	--	--
Grand fir	--	--	m	m	m	M[3]	M[3]	M	--	--	M[3]
Incense-cedar	--	--	--	--	m	m	m	--	--	--	m

[1] The higher elevation forest zones in which true firs and hemlocks are the climax species (see text footnotes 2 and 5). Symbols indicate the following: M = major species; m = minor species.

[2] See text footnote 6.

[3] See text footnote 7.

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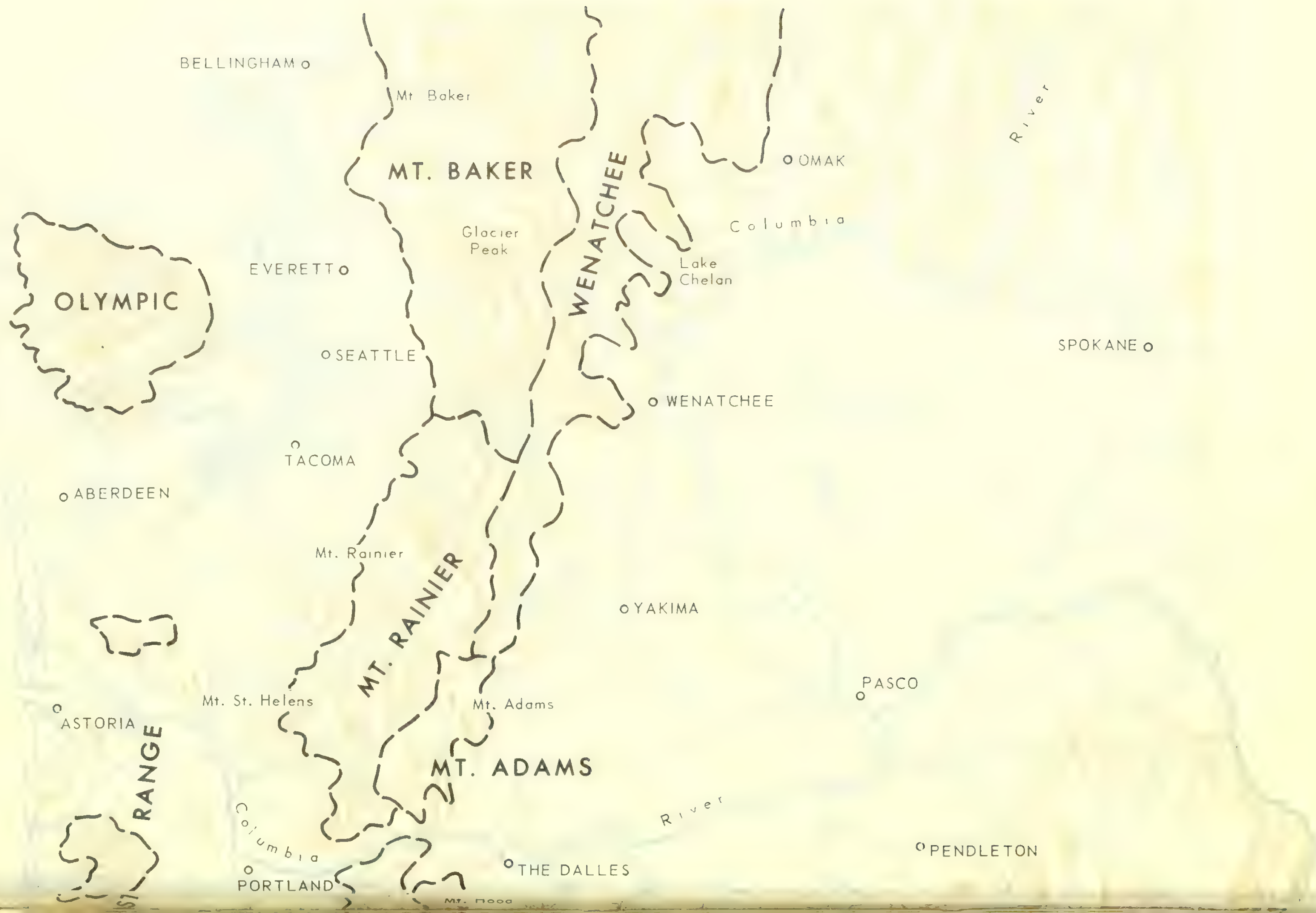
[5] The higher elevation forest zones in which true firs and hemlocks are the climax species. These include the following life zones found in various parts of the mountain ranges: Pacific Silver Fir-Western Hemlock, Pacific Silver Fir-Mountain Hemlock, Shasta Red Fir, Mountain Hemlock, and Subalpine Fir-Englemann Spruce Zones. These life zones are based on the climax tree species. The zones and their geographic distribution will be discussed in future publications.


BELLINGHAM
Mt Baker
MT. BAKER
Glacier Peak
WENATCHEE
OMAK
River
Columbia
Lake Chelan
OLYMPIC
EVERETT
SEATTLE
SPOKANE
WENATCHEE
TACOMA
ABERDEEN
Mt. Rainier
MT. RAINIER
YAKIMA
Mt. St. Helens
Mt. Adams
PASCO
ASTORIA
RANGE
MT. ADAMS
Columbia
River
PENDLETON
PORTLAND
THE DALLES
Mt. Hood

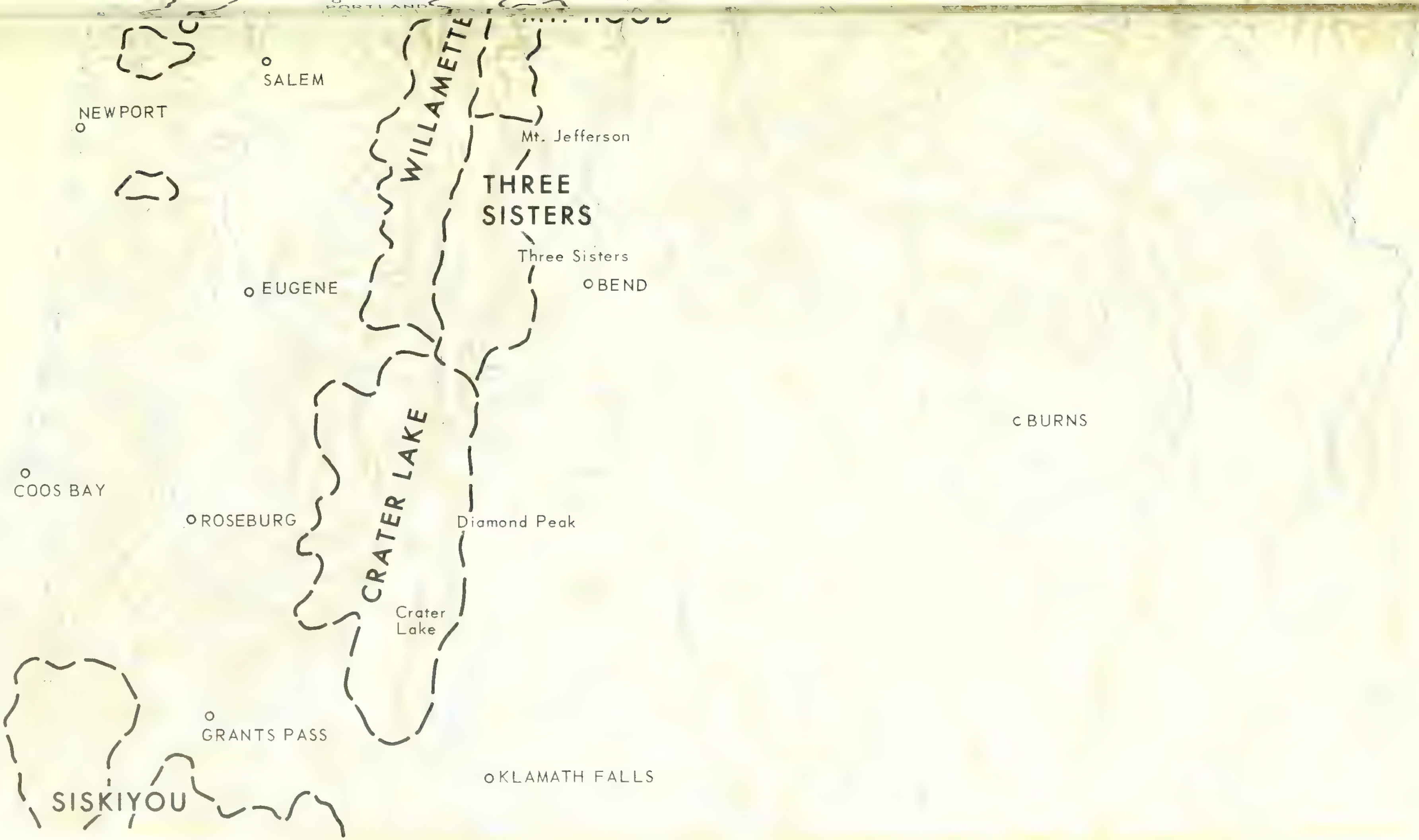


Figure 1.--The boundaries of the 11 ecological provinces of the true fir-hemlock forests recognized in this paper. These are based on differences in geology, topography, soil parent materials, climate, and vegetation.

Extensive forests of Pacific silver fir and western hemlock occupy the Mount Baker Province, not only at higher elevations but also at moderate to low elevations on slopes and valley bottoms (fig. 6). True fir-hemlock forests, the most important forest resource in this province, provide a large part of the raw material for the local pulp and paper industry. A recent inventory (MacLean and Hightree 1959) reveals that 65 percent of the sawtimber volume present in Skagit and Whatcom Counties is Pacific silver fir and western hemlock. At highest elevations, the major forest species are Pacific silver fir and mountain hemlock. Western redcedar and Alaska-cedar are common associated species on moist sites at lower and higher elevations, respectively. Seral stands of Douglas-fir are common on recently disturbed sites at low and moderate elevations. Noble fir is found in scattered stands and only in the southern half of the province.

Forests of the true fir-hemlock zone in the Olympic Mountains are very similar to those found in the Mount Baker Province. In mature stands, the major species are Pacific silver fir and western and mountain hemlocks.

Forests in the Wenatchee Province reflect less precipitation and a more continental climate than is found on the western slopes of the Cascade Range. Pacific silver fir and mountain hemlock occur only along the western edges of this province. Abundant species in the true fir-hemlock zone of this province are subalpine fir, Engelmann spruce, lodgepole pine, western white pine, western larch, and grand fir. Forests are very much like those described in the Engelmann spruce-subalpine fir zone of northern Idaho (Daubenmire 1952). They occupy high peaks and ridges, and sometimes valley bottoms due to air drainage patterns. Fire has been a more important factor than in the adjacent Mount Baker Province and seral stands of variable composition are extensive. Also, much of the high-elevation area is broken, rocky country along the summits and slopes of ridges and does not support closed forest stands.

True fir-hemlock forests of the Mount Rainier Province are more diverse in composition than those of the Mount Baker Province. Although extensive, they are more insular in character and tend to occur as disjunct stands on higher peaks and ridges. This is because areas of sufficient elevation to support true fir-hemlock forests (which do not extend to as low an elevation in this province) are usually not continuous as a result of the ridge and valley topography. Pacific silver fir, western hemlock, noble fir, and mountain hemlock are the most important species in mature stands. Douglas-fir forests are common in the true fir-hemlock zone, but are eventually succeeded by forests of Pacific silver fir and hemlock (fig. 7). Western white pine is only a minor constituent of the forests, but individual specimens attain excellent development. Alaska-cedar is locally abundant on cooler and moister sites where specimens compare favorably with associated species (fig. 8).

Forest stands in the true fir-hemlock zone of the Willamette Province are very similar to those in the Mount Rainier Province. They are even more insular in nature, however, because of the increased elevation at which the true fir-hemlock zone occurs.

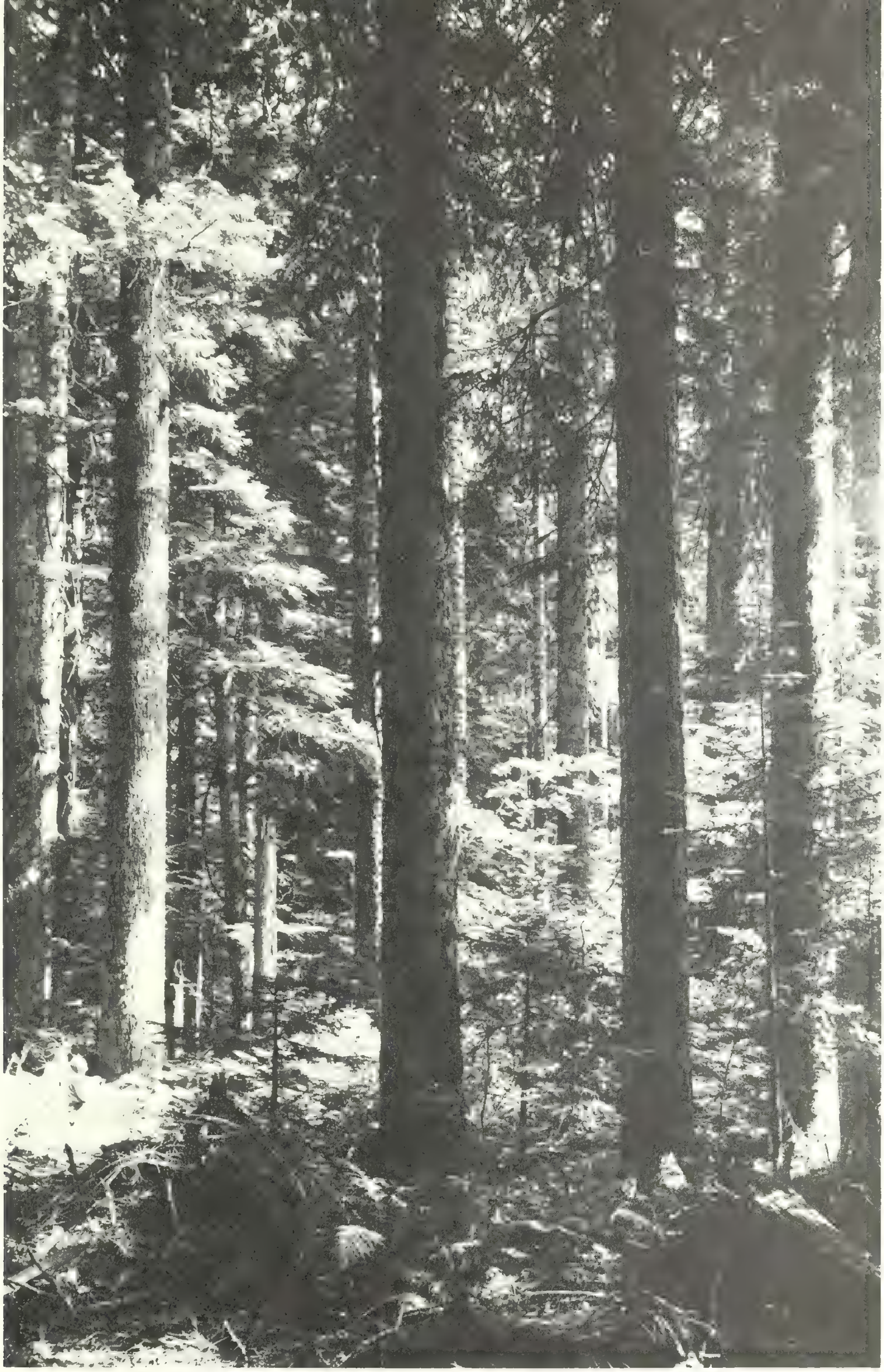


Figure 6.--A Pacific silver fir-western hemlock stand in the Mount Baker Province.

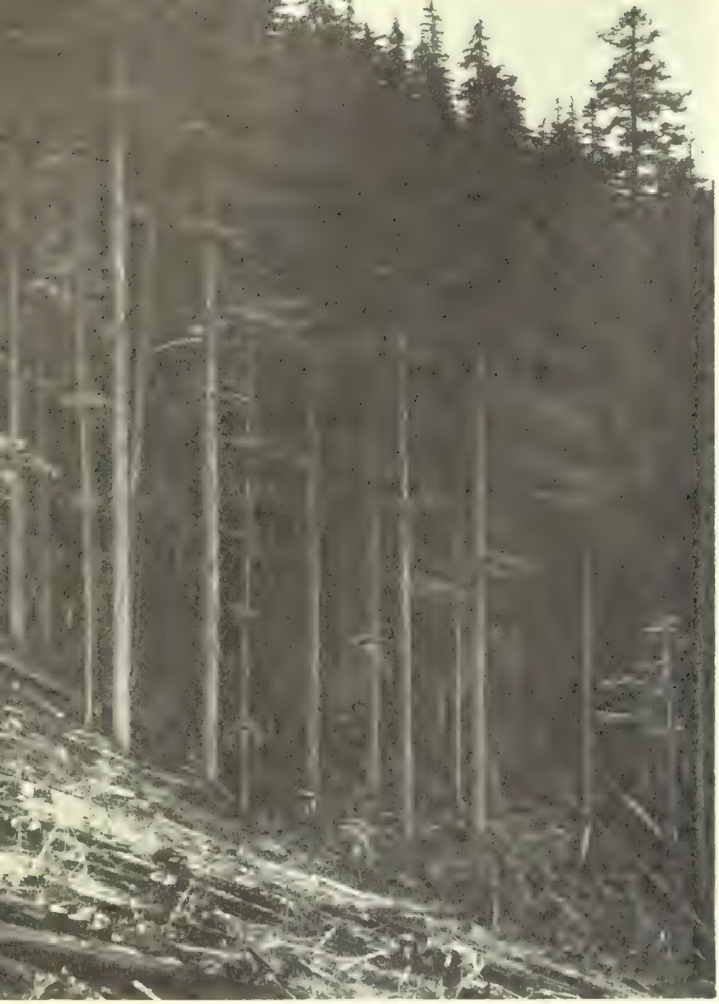


Figure 7.--A nearly pure western hemlock forest growing at 4,500-foot elevation in the Mount Rainier Province. The understory regeneration is entirely Pacific silver fir. Note the noble fir on the right which is emergent above the western hemlock canopy.

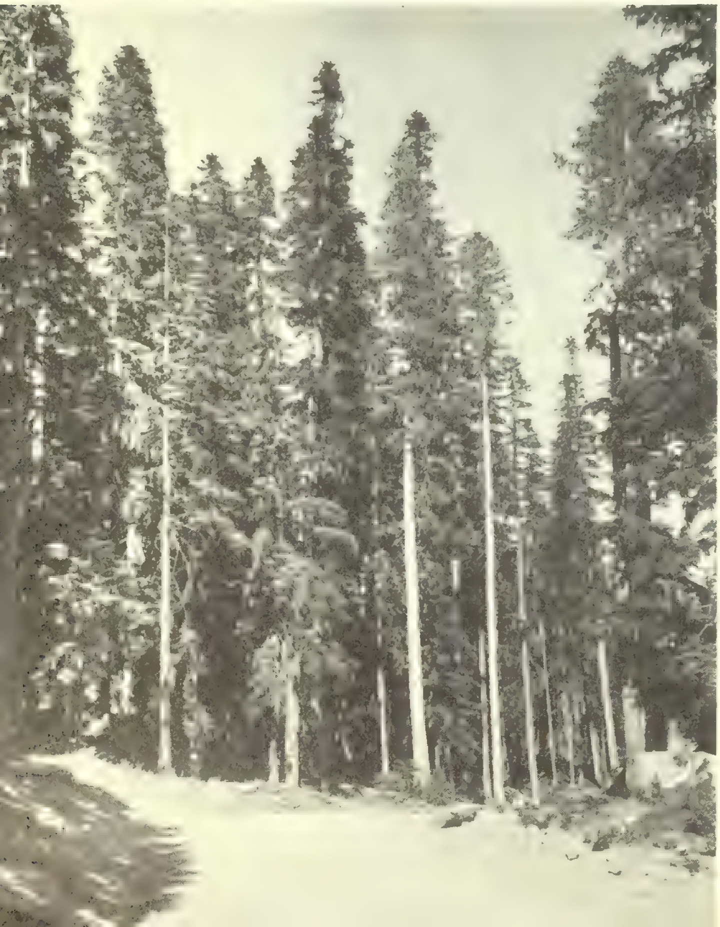


Figure 8.--Pacific silver fir and Alaska-cedar are often associated at high elevations in the Mount Rainier Province. In this stand, fir averages 165 feet tall and cedar, 135 feet tall.

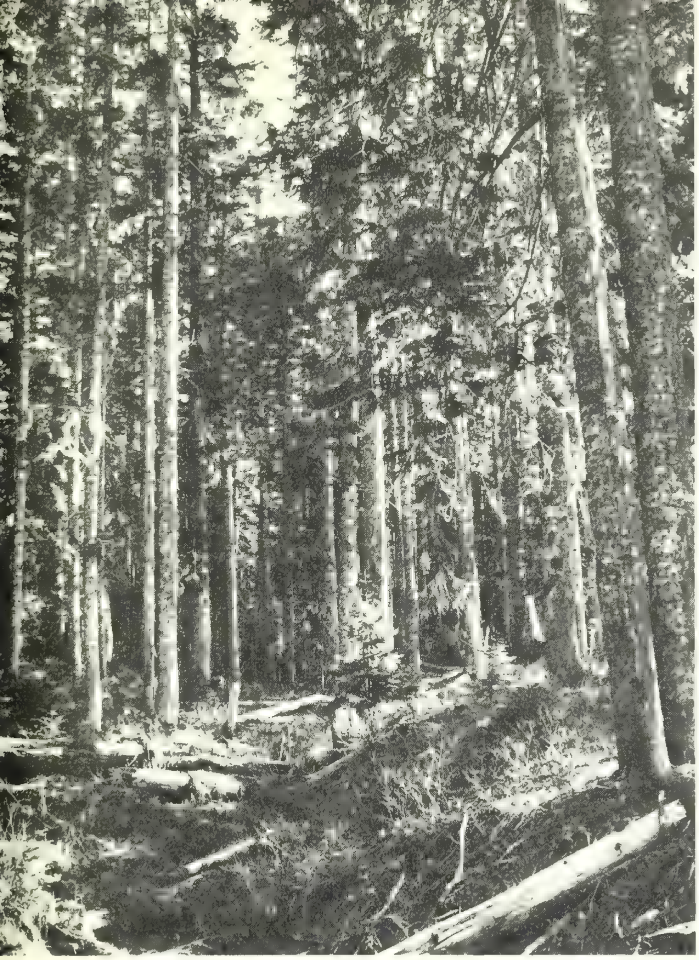


Figure 9.--Dense, young-growth stand of Pacific silver fir in the Willamette Province.

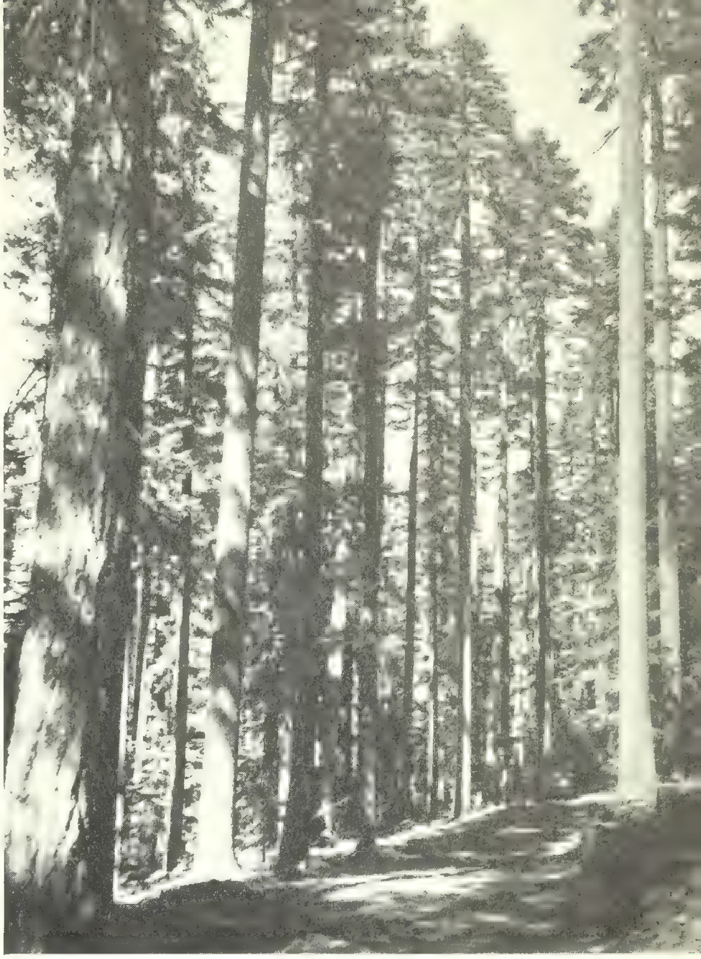


Figure 10.--Pure stand of old-growth noble fir in the Mount Hood Province. Dominant trees are 135 to 145 feet tall.

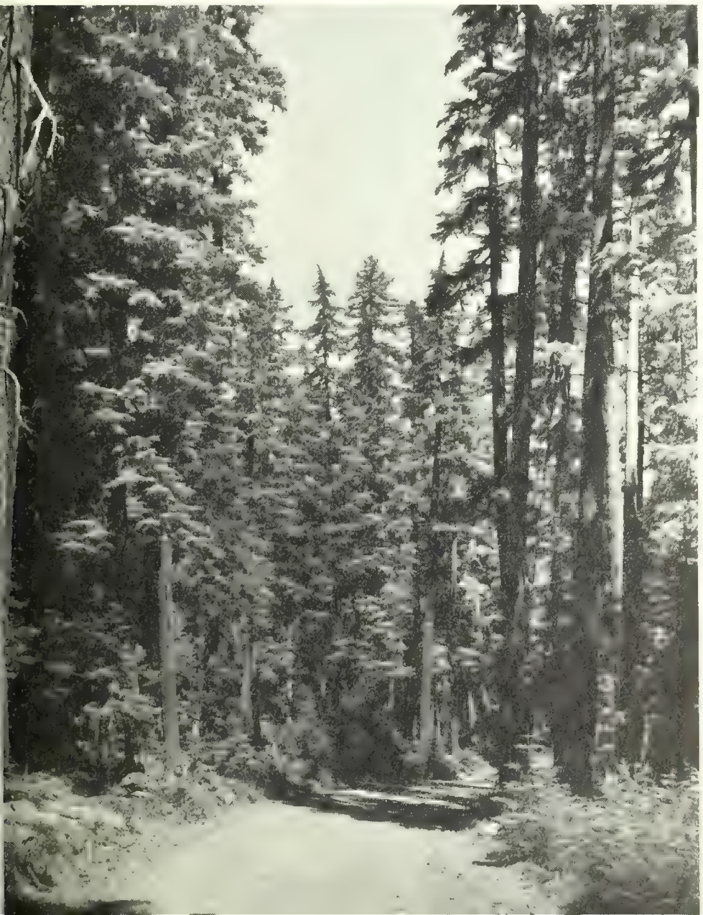


Figure 11.--This stand of western and mountain hemlocks, Pacific silver and noble firs, and Douglas-fir in the Mount Hood Province illustrates the highly variable nature of true fir-hemlock forests.

Important species in mature stands are Pacific silver fir (fig. 9), noble fir, and western hemlock; mountain hemlock is present in quantity only at the highest elevations. Douglas-fir, western redcedar, and western white pine are common as remnants in older stands or as major constituents of young stands.

True fir-hemlock forests occupy extensive contiguous areas in the rolling, high country of the Mount Adams Province. In the moister western parts of the province, mature forests are composed of Pacific silver fir and western and mountain hemlock. Toward the eastern edges of the province, mature forests of mountain hemlock predominate. Excellent stands of noble fir are common on certain localized habitats. The true fir-hemlock zone in this province has suffered from extensive wildfire over the last century and, for this reason, seral stands with various combinations of lodgepole pine, western white pine, subalpine fir, grand fir, Engelmann spruce, western larch, and Douglas-fir are common. Western white pine attains major importance in this province and in the High Cascades provinces of Oregon.

Forests of the true fir-hemlock zone of the Mount Hood Province are similar (figs. 10 and 11) except that Pacific silver fir is less important and the hemlocks more important than in the Mount Adams area. Old burned-over tracts are common at high elevations in this province (fig. 12).

Forests in the Three Sisters Province differ noticeably from those further north. Western hemlock is much less important and mountain hemlock relatively more important. Pacific silver fir, although still a major climax species, is less common. Noble fir is practically absent except in one or two localities. Stands of lodgepole pine, subalpine fir, and western white pine are common on old burns (fig. 10); Douglas-fir is less common as a seral species, and western larch is absent.

A major change in the character of true fir-hemlock forests takes place in the Crater Lake Province. Western hemlock and Pacific silver fir become relatively inconspicuous species with limited distribution. Major species are Shasta red fir,[6] mountain hemlock, western white pine, lodgepole pine, and grand fir[7] (fig. 13). In the absence of the tolerant Pacific silver fir and western hemlock, climax species are

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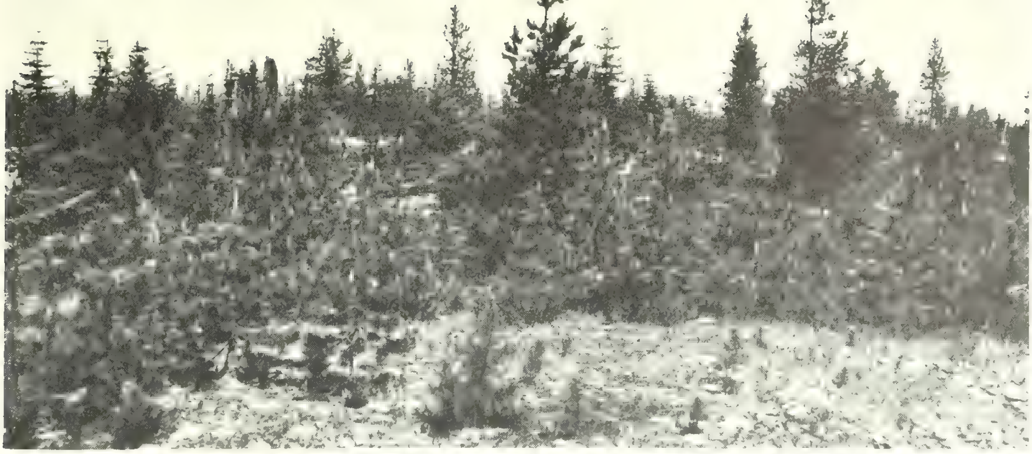
[6] Shasta red fir in southern Oregon is a morphologically variable complex, sometimes referred to as noble fir. Hybrid populations are probably present, having resulted from mingling of noble fir and California red fir *(Abies magnifica)*. For discussion of this complex, see Franklin (1964) and Parker (1963). Because of differences in ecological characteristics between the fir found in southern Oregon and noble fir found in Washington and northern Oregon, and until the identity of the former has been satisfactorily established by taxonomic study, the bulk of the southern Oregon fir will be referred to as Shasta red fir, and noble fir will be considered to be a minor component of these forests.

[7] The grand fir here is a morphologically variable complex, referred to by various authors as both grand fir and white fir *(Abies concolor)*. Populations exhibit characteristics of both species in variable proportions and may represent hybrids.



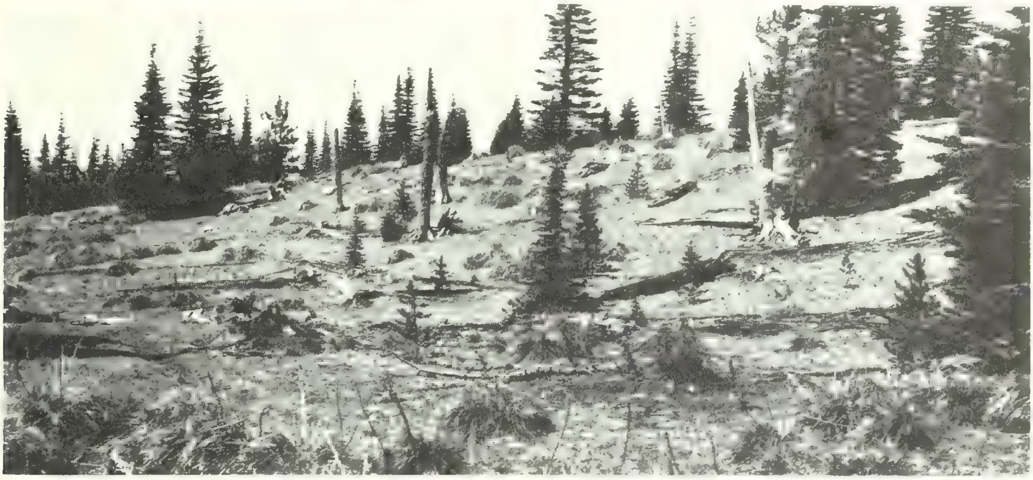


Figure 12.--Many high-elevation tracts within the High Cascades provinces have been burned by wildfires over the last century. Top: Sherar Burn in the Mount Hood Province, Mount Hood National Forest. Bottom: an old burn on slopes of Mount Washington, Willamette National Forest, which has regenerated very slowly following burning.

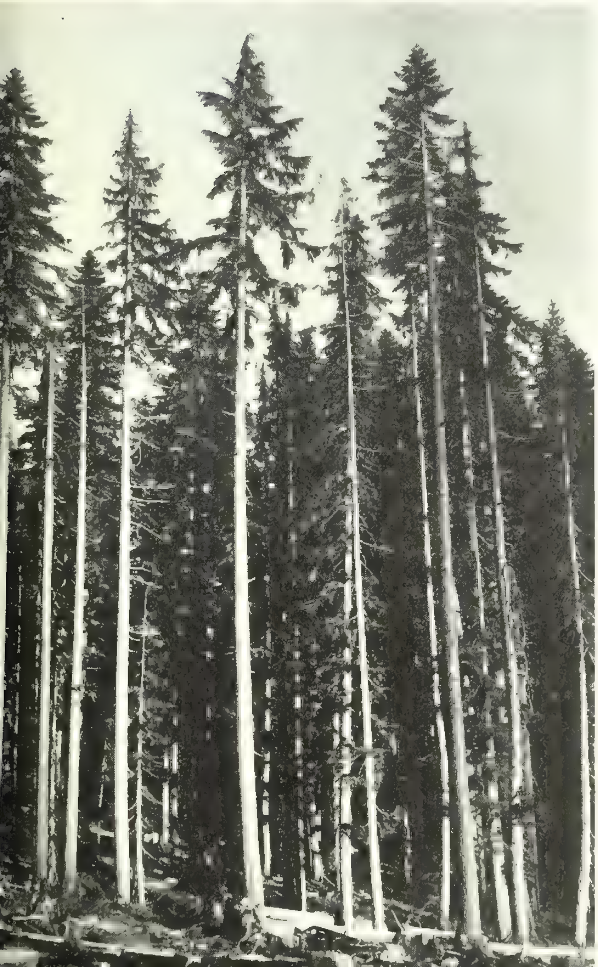


Figure 13.--In the Crater Lake and Siskiyou Provinces, Shasta red fir (trees in foreground on extreme right and left) and mountain hemlock (two trees in center foreground) are the most important species in the true fir-hemlock forests.

apparently mountain hemlock and Shasta red fir at high elevations and Shasta red fir and grand fir at lower elevations in the true fir-hemlock zone. Mountain hemlock attains its maximum importance relative to other upper-slope species in the high, rolling country of this province, and it forms dense, pure or nearly pure stands covering many square miles (fig. 14). Lodgepole pine also forms pure stands (mainly seral) over extensive tracts within the true fir-hemlock zone, expecially on eastern slopes of the Cascade Range.[8]

Forests of the Siskiyou Mountains are similar in composition to those in the Crater Lake Province. True fir-hemlock forests are not extensive, however, because most high-elevation tracts are highly insular and often not suited edaphically or topographically for closed forest stands. Shasta red fir, mountain hemlock, grand fir, and western white pine are the major species. Shasta red fir and mountain hemlock are typical of highest elevations and Shasta red fir and grand fir of lowest elevations in the true fir-hemlock zone.

True fir-hemlock forests in the Coast Ranges occur at very scattered locations, generally on the highest peaks and ridges. Occasional stands of Pacific silver fir and more frequently encountered isolated stands of noble fir in the northern Oregon Coast Ranges and in Washington's Willapa Hills represent the true fir-hemlock forests in this province.

Thus, four general groups of provinces can be recognized on the basis of forest composition in the true fir-hemlock zone: (1) Mount Baker, Mount Rainier, Willamette, Olympic, and Coast Range Provinces, where Pacific silver fir, western hemlock, and noble fir (in three of the five provinces) are the characteristic and important species and in which seral stands in true fir-hemlock zones are often typical, west-side Douglas-fir forests; (2) Wenatchee Province, where forest composition is very similar to the spruce-fir zone of the northern Rocky Mountains; (3) Mount Adams, Mount Hood, and Three Sisters Provinces, where climax species are the more mesic Pacific silver fir and hemlocks, but in which the important seral species indicate interior influences (subalpine fir, lodgepole pine, western white pine, western larch, e.g., in addition to Douglas-fir); and (4) Crater Lake and Siskiyou Provinces, where mountain hemlock and Shasta red fir are the most important species.

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[8] Lodgepole pine stands may be climax on certain soils and physiographic positions within the true fir-hemlock zone. This is certainly the case at lower elevations (e.g., in the ponderosa pine zone) on the east side of the southern Oregon Cascade Range (Dyrness and Youngberg 1958).

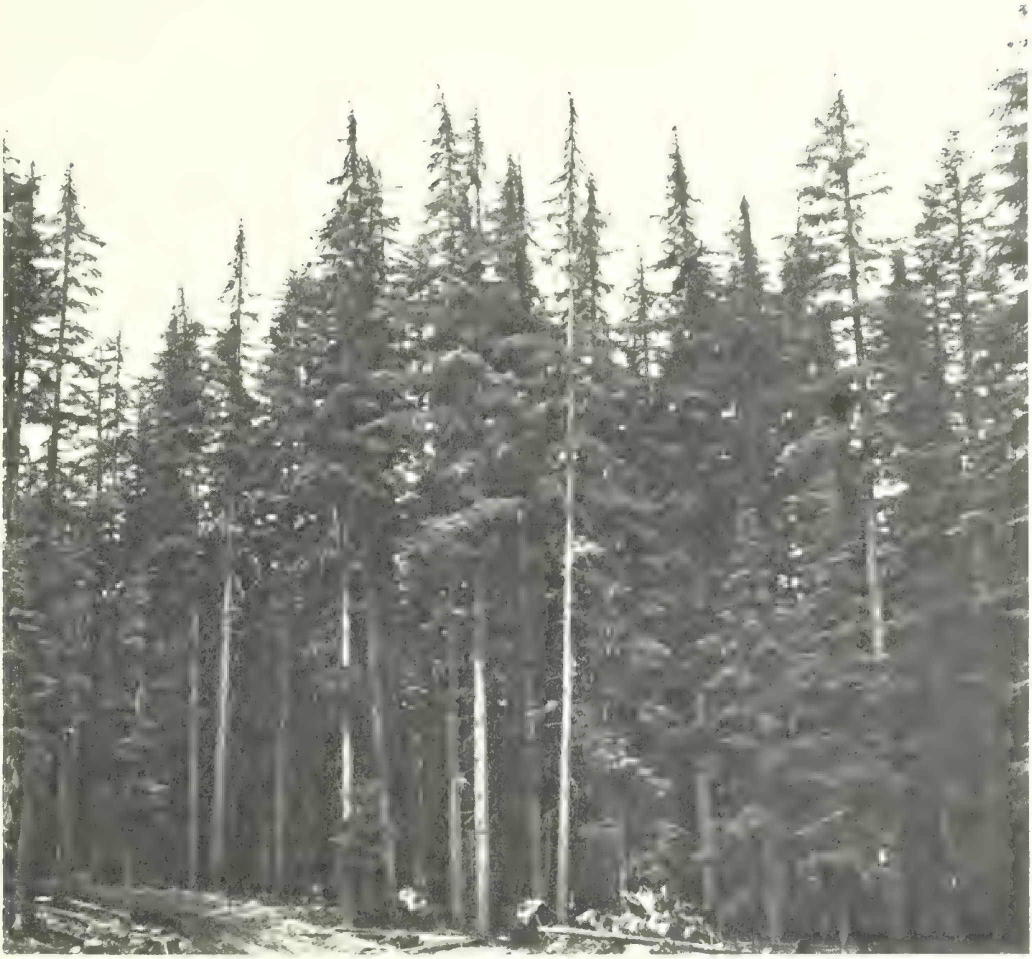


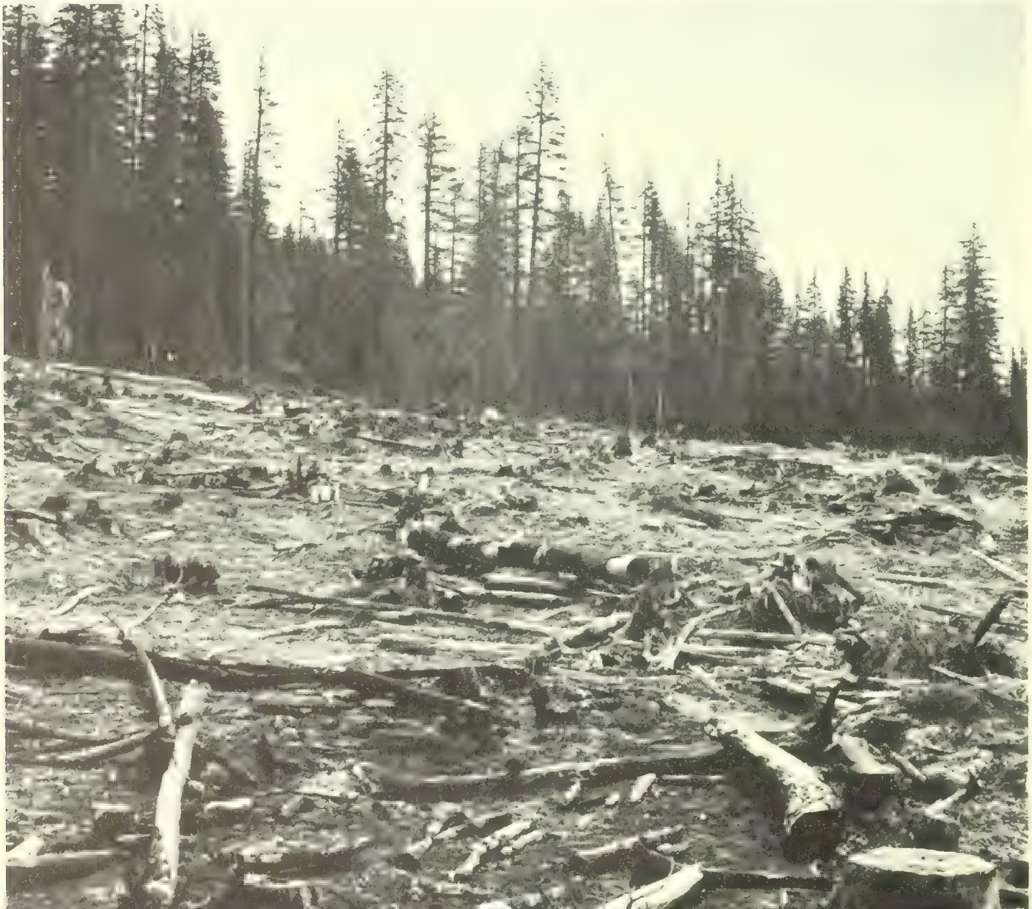
Figure 14.--Mountain hemlock attains major importance in the true fir-hemlock forests of the Crater Lake Province, forming pure stands over extensive areas.

Application

This ecological province classification can be of immediate use to forest managers and researchers working in forests of the true fir-hemlock zone. For forest managers, the provinces provide a geographic basis for making generalized management decisions. For the researcher, classification provides a broad basis for stratifying study areas and identifying and isolating problems in true fir-hemlock forest management. Following are some examples of management problems which appear to be directly related to particular ecologic provinces.

The most acute regeneration problems in the true fir-hemlock forests are in the High Cascades provinces from Mount Adams to southern Oregon (fig. 15). On the other hand, regeneration tends to be easier to obtain in western slope provinces--Mount Baker, Mount Rainier, Willamette--provided cutting units are kept small enough to allow for adequate, natural seed fall.

Figure 15.-- Clearcut tracts in true fir-hemlock forests of the High Cascades provinces, such as this one near Crater Lake, are sometimes difficult to regenerate.



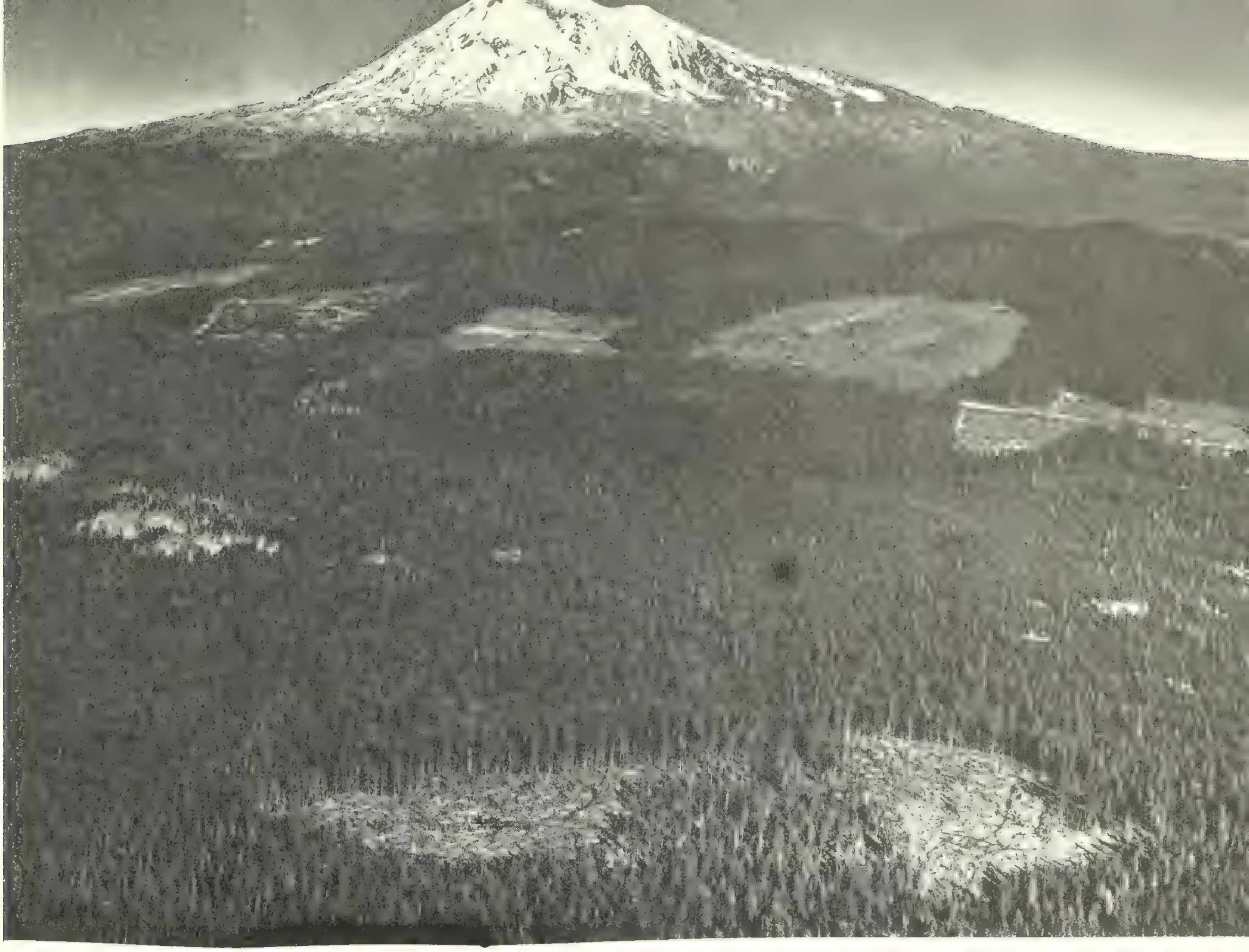


Figure 16.--True fir-hemlock forests in the High Cascades provinces occur on topography which allows for easy access and application of a variety of silvicultural systems.

Growth potential of true fir-hemlock forests are related to provinces. As one example, old-growth noble fir in the Mount Rainier Province attains heights of more than 250 feet on best sites but only 150 feet in the adjacent Mount Adams (High Cascades) Province, as indicated by preliminary data.

Protection problems are often related to provinces. Indian paint fungus *(Echinodontium tinctorum)* is a rot responsible for heavy cull in old-growth western hemlock stands in the High Cascades provinces but is of minor consequence in adjacent Western Cascades provinces. Destruction of Pacific silver fir by balsam woolly aphid *(Chermes piceae)* has been encountered only on high-quality Pacific silver fir sites in the Mount Rainier Province; none has been encountered in the adjacent Mount Adams Province in which Pacific silver fir is also widespread. Damage to mountain hemlock by *Poria wierii* has been noted only in the Three Sisters and Crater Lake Provinces.

Provinces may also provide a basis for species selection. For example, the Wenatchee Province and four High Cascades provinces appear to be favorable areas for the management of western white pine. In these areas, western white pine generally appears to be one of the fastest growing species in the true fir-hemlock zone.

Finally, the provinces provide a basis for comparing timber management potential of true fir-hemlock forests in various parts of the region. On western slopes of the Washington Cascades, these forests are extensive and appear amenable to management with no particularly difficult problems except in local areas. In the Wenatchee Province, the true fir-hemlock forests are much less valuable compared with the total timber resource and often occupy areas which are difficult of access and management. The High Cascades provinces contain extensive tracts of true fir-hemlock forests on topography which allows easy access and application of a variety of silvicultural systems (fig. 16), although the growth potential of these true fir-hemlock forests is somewhat below those found in the adjacent Western Cascades provinces.

Further Subdivision

Subdivision, simplification, or other refinements of this tentative classification may prove desirable as more data become available on vegetational and environmental characteristics of the true fir-hemlock forests. In the Mount Rainier Province, for example, comparatively recent creation of Mount St. Helens has greatly modified Western Cascades topography and soil parent materials over a considerable area in the immediate vicinity of the mountain, especially to the northeast where much of the volcanic ejecta was deposited. This type of variation within the broader geographic units must be considered when the vegetational and environmental features of provinces are studied or when management recommendations for provinces are made.

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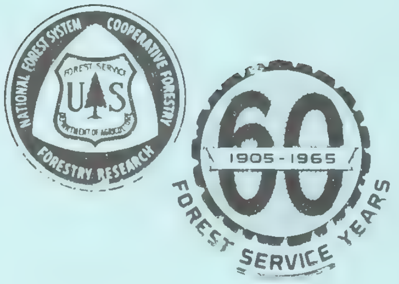
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HIGH-LEAD LOGGING COSTS

as related to LOG SIZE
and other VARIABLES

Thomas C. Adams

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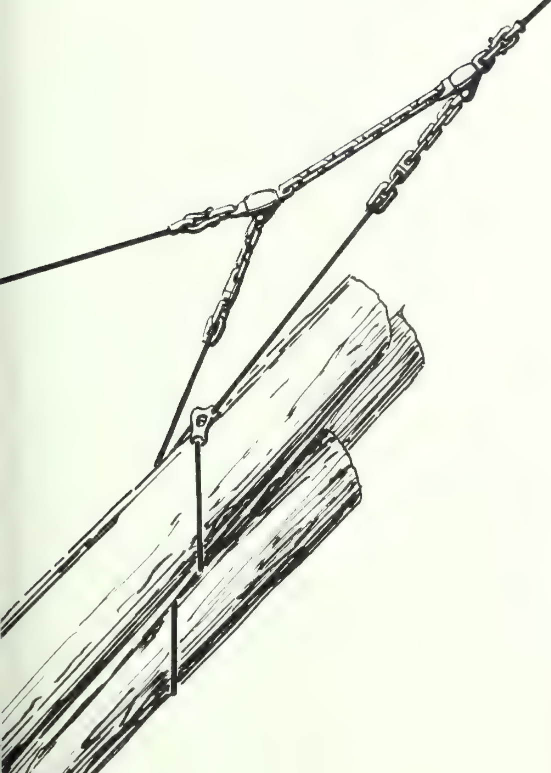

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Introduction

Logging managers and the firms or agencies of which they are a part are constantly seeking to reduce costs and to increase utilization of the available raw materials in the woods. Most managers in other types of business spend a good share of their time keeping track of manufacturing and marketing costs, and cost accounting methods are available for identification and control of specific costs or individual items or classes. Yet when it comes to logging, frequently the only cost information available is an average cost for each function such as felling and bucking, yarding, loading, and hauling, derived by dividing the total functional cost by total volume of production. This information is useful, but even more useful would be knowledge of the range of logging costs and conversion values related to log volume, diameter, yarding distance, terrain features, and other variables (figs. 1 and 2).

Figure 1.—Large logs have relatively low logging costs per thousand board feet.

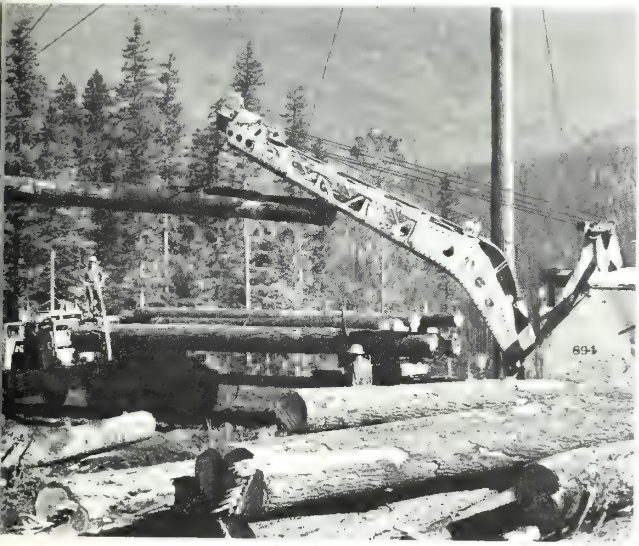
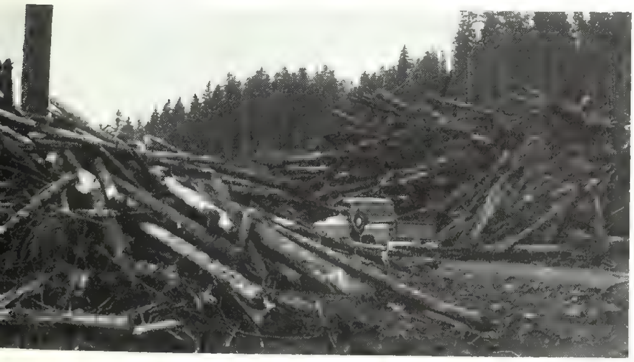


Figure 2.—Small pulpwood logs have relatively high logging costs. Economic studies are needed in each situation to determine conversion values for small-sized pieces.



A shortcoming of average costs is that they are a mixture of high and low costs. A given average cost may seem satisfactory and in line with profitable operations, yet a breakdown into component costs may reveal individual cost situations that are not satisfactory and not profitable.

This report presents the findings from a single study of high-lead logging covering several settings and crews. Results should be applicable to other operations having similar conditions of stand composition, available equipment, utilization outlets, and costs. The results are also a useful aid toward understanding the opportunities and limitations for more complete logging utilization throughout the region. They can provide a basis for determination of economic utilization limits over a wide variety of given conditions.

Of course, no simple rules can be laid down that will apply exactly to all operations and to all areas. There is a gradual transition from highly profitable logs down through those that are barely profitable or just barely unprofitable, and on to those that are definitely unprofitable. This report indicates the operating times, costs, and values that were developed for the conditions in this study and should provide a valuable guideline for modification of results or for new studies covering other operating conditions. A major objective has been to outline the principles and methodology on which such studies may be based.

Marginal Cost Concepts

Every logging operation has some logs so small that they are not worth the cost of logging. But how can the economic limits be identified? The answer lies in accurately determining the value of logs of different volume sizes and in comparing these values with the **extra** costs of harvesting these logs. The key question for any particular log concerns only the actual value of that log compared with the marginal or extra cost of taking it over not taking it. In particular, costs of overhead, road construction, preparation of landings, and other similar fixed costs have no bearing on this decision if these fixed costs are the same whether or not the log in question is taken. Variable costs or direct costs are those incurred only if a given log is taken.

These principles are frequently followed in practice but usually cannot be supported by any cost data, because accounting records are generally in terms of average or full costs which include both fixed and variable costs for all logs collectively.

Judgment and experience of the logging manager can do a great deal toward determining which logs to take and which to leave and toward selecting the operating method that best suits the timber and terrain conditions. However, explicit data developed from time studies can show some of the essential relationships more clearly and guide the logging manager toward sharpening his judgment and operating skills.

Time-study techniques together with modern regression analysis make it possible to work with definite measured or calculated values over the full range of individual variables and permit combining the effects of several variables in one mathematical formula.

In its simplest terms, the procedure of marginal cost analysis is to (1) calculate labor and equipment costs per hour or per minute, (2) measure operating times per turn or per log, (3) convert these to production per hour or per minute for different log sizes, and (4) divide direct cost per time unit by production per time unit to arrive at a direct cost per unit volume.

Labor and equipment costs are expressed in this study as hourly costs. Depreciation and related items of interest, taxes, and insurance are considered a part of the hourly equipment costs, and therefore are in this sense "direct" costs because they are directly related to choice of equipment and to a more or less fixed number of operating hours per year. This concept may be called the "fixed time convention." Such costs would be truly fixed costs and left out only if the equipment would otherwise be idle, in which case only the extra fuel cost, for example, might be charged for an extra hour's use of a yarder or loading machine.

Thus, the equipment costs may be considered direct or variable costs in the sense that there is a choice of remaining on the current setting an extra amount of time to remove an extra volume of smaller logs or of moving on to start another setting a little sooner.

Crew transportation and payroll overhead are similarly treated in this report as a part of direct hourly wage cost.[1] It may be helpful to visualize this treatment if one thinks of the smallest size class of logs as coming out all in the last few days of the year. Clearly, the extra costs of crew transportation and payroll overhead would apply to the extra full days' or weeks' time spent. Therefore, it should make no difference whether the small logs were removed all together in several full days or, as in actual practice, spread individually in mixture with larger logs all through the year; the small logs must still bear their share of crew transportation and payroll overhead costs, prorated on the basis of time (not volume).

Alternative cost concepts are discussed in Appendix B.

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[1] As used here, payroll overhead includes social security, unemployment compensation, accident insurance, vacation pay, pension, and health and welfare programs. It excludes hiring and firing costs and costs of record keeping.

Description of Field Study near Cosmopolis, Wash.

This study was conducted on Weyerhaeuser Co.'s Clemons Tree Farm, near Cosmopolis, Wash., in the spring of 1961. Time-study observations were made on seven clearcut settings in 110-year-old western hemlock. Associated species included true firs, Sitka spruce, western redcedar, and a small amount of Douglas-fir. The settings varied from 5.7 to 14.0 acres in extent, with an average of 10.4 acres. External yarding distances ranged from 480 to 740 feet. The settings were located along a ridgetop at approximately 800 feet above sea level. Slopes of the settings were mostly 30 to 40 percent, although slope of individual turns ranged from level to more than 70 percent (all data were from uphill yarding).

Logging Methods and Utilization Standards

The study included two types of high-lead logging: (1) a two-stage relog method where, after clearcutting, all logs down to 10 inches in diameter by 26 feet in length were yarded by standard high-lead equipment and a seven-man crew and then, from the same spar tree, material down to 4 inches by 8 feet was relogged with lighter high-lead equipment and a five-man crew; (2) clean logging to a 4-inch by 8-foot minimum with a single seven-man operation.[2] In the balance of this report, both the terms "regular yarding" and "regular logging" will refer to the clean-logging method or the first stage of the two-stage method. The seven-man crew consisted of hook tender, rigging slinger, two choker setters, signalman, chaser, and yarder engineer. The five-man crew had no rigging slinger and only one choker setter.

Relogging in three settings was to a small cold deck (fig. 3); the fourth relog setting was "hot-loaded."

Loading for the regular logging operations was with a so-called 1-yard shovel-type loader

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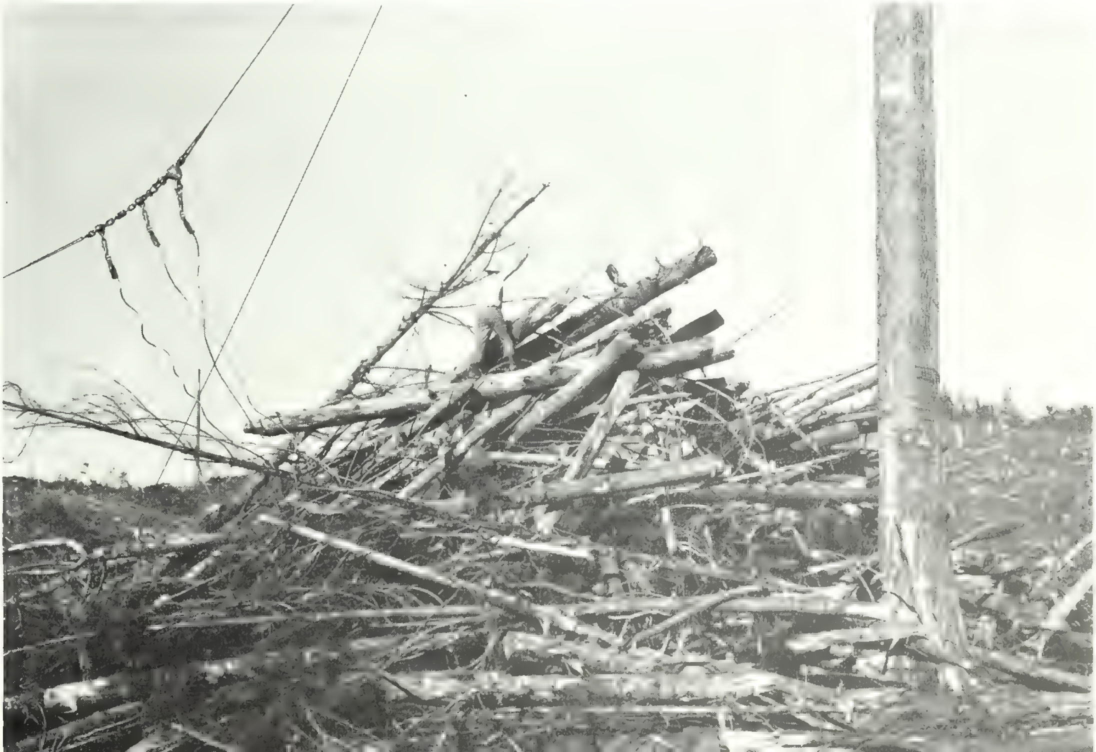
[2] Adams, Thomas C. Economic comparison of relogging and clean logging in mature hemlock. 1965. (In preparation for publication, Pac. NW. Forest & Range Expt. Sta., U. S. Forest Serv., Portland, Oreg.).

Figure 3.—Tops, small trees, and broken chunks for pulpwood may be cold-decked in a relogging operation.



equipped with heel boom and tong line. The relogging used a similar loader in the 3/4-yard size. A portable sled or crib arrangement was available at each landing for making up partial loads of pulpwood up to 20 feet in length.

Hauling was chiefly with standard diesel semitrailer log trucks. Relog hauling was with separated short truck and trailer combinations taking up to 26-foot lengths on the truck and up to 20-foot lengths on the trailer. An extra trailer was used in the relogging so that loading could be continued while the truck and trailer unit was enroute.

Both clean-logged and relog settings had a pulpwood crib or sled unit at the landing so that small pieces could be assembled into partial loads during free time.

Loaders were equipped for radio communication with the Cosmopolis office and field cars. This facilitated communication and coordinated dispatching of trucks. Also, the fact that two other logging sides were loading in the same vicinity gave flexibility to the hauling operations.

Study observations were made and recorded during the period from January through April. A good share of the days had rain, but crews were well adjusted to wet conditions and production was not considered to be slowed on this account.

Time Study of Yarding and Loading

Times were measured by stopwatch for the various elements of yarding and loading operations by number of logs, yarding distance, and size of logs. Felling and bucking times were not measured, as the study concerned only times and costs for individual logs after the felling and bucking operations. Most settings had at least 2 complete days of timing so as to include delay times and to avoid different production rates for different times of day. These detailed time data permitted calculation of individual time per turn and time per log.

In addition, gross time was recorded daily by the yarder and loader operators to indicate working hours on each setting, together with time and reason for all delays over 10 minutes.

YARDING TIMES.—The observer recorded the number of logs per turn, hauling distance, time out and in, unhooking time, and any delay time. Supplemental times of changing cable roads and corner blocks were also recorded. Delay times in yarding were not used in developing unit costs because they are considered to be haphazard in occurrence, unpredictable in amount, and unrelated to log size, at least in the smaller log sizes under examination where the critical economic margin lies. Supplemental times for changing cable roads and corner blocks were also excluded, as these are fixed costs per yarding sector and not related to the extra time to bring in any given log.

Although delay times and supplemental times were not used in developing unit costs, they were recorded and may be summarized as follows:

	Regular yarding	Relog yarding
	(Hours per 8-hour day)	
Operating delays[1]	0.512	0.233
Supplemental times for changing cable roads and corner blocks	.661	1.392
Actual yarding time	6.695	6.243
Machine time	7.868	7.868
Breakdown	.132	.132
Total all time	8.000	8.000

[1] Operating delays include hangups, changing guy lines, swinging blocks, moving yarder, and minor delays at the landing.

Or, expressed in hours and minutes:

	Regular yarding	Relog yarding
	(Hours and minutes per 8-hour day)	
Operating delays[1]	31 min.	14 min.
Supplemental time	40 min.	1 hr. 24 min.
Actual yarding time	6 hr. 41 min.	6 hr. 14 min.
Machine time	7 hr. 52 min.	7 hr. 52 min.
Breakdown	8 min.	8 min.
Total	8 hr. 0 min.	8 hr. 0 min.

[1] Operating delays include hangups, changing guy lines, swinging blocks, moving yarder, and minor delays at the landing.

These delay times were probably lower than might be expected on average operations in the region, because (1) maximum yarding distances were generally kept under 700 feet, (2) there were no unusual terrain difficulties, and (3) radio communication, plus the presence of a field supervisor and two other logging sides in the vicinity, gave flexibility to operations in case of breakdown or need for spare chokers or other parts, assistance in moving yarder, swinging blocks, etc.

Yarding distance was estimated to the nearest 10 feet up to 100 feet and by reference to colored markers at 100-foot intervals beyond. Diameter and length of each log were estimated by the observer, who made frequent check measurements at the landing when time permitted and when there was no interference with operations.

LOADING TIME.—The following elements were measured and recorded:

a. Loading time per "pickup" cycle
b. Number of pieces in each pickup (normally one piece)
c. Estimated diameter and length of each piece
d. Whether load was to truck, separate trailer, sled, deck, or other spot
e. Delay time with cause
f. Number of pieces per truckload and type of load (pulpwood, saw logs, etc.)
g. Times of arrival, beginning of loading, end of loading, and departure for each truck.

Regression Analysis

Factors determining yarding and unhooking times were analyzed by multiple regression techniques, using electronic data processing and standard statistical procedures. Loading time was analyzed by simple regression, relating loading time to log volume. Separate runs were made for regular yarding and for relog yarding elements.

Regression analysis included the following independent variables:

a. For yarding time,
- D = slope distance in feet
- D^2 = (slope distance)^2
- V = volume per turn, in cubic feet
- DV = slope distance times volume per turn
- S = slope, in percent
- VS = volume per turn times slope
- C = number of chokers
- N = number of logs per turn.

b. For unhooking time,
- C = number of chokers
- V = volume per turn, in cubic feet
- N = number of logs per turn
- CV = number of chokers times volume per turn.

c. For loading time,
- V = volume per log, in cubic feet.

Resulting Equations

From the above listing, only those elements were retained that contributed significantly toward explanation of total variance.

Resulting equations whose elements showed acceptable levels of significance were as follows (Y = round-trip turn time in minutes, including choker-set time but excluding unhooking time):

a. Regular yarding (fig. 4),[3]

$$Y_1 = 1.471 + 0.007237D - 0.000003448D^2 + 0.003771V + 0.000008633DV - 0.1402N.$$

b. Relog yarding (fig. 5),[4]

$$Y_2 = 1.963 + 0.006423D + 0.007297V + 0.1629N.$$

c. Unhooking time, regular yarding,

$$Y_3 = \text{minutes unhooking time, from time line stops to the beginning of new turn cycle} = 0.2827 + 0.1150C + 0.001519V + 0.05806N.$$

This equation yields the following values:

Turn volume	Two chokers, two logs	Three chokers, three logs
(Cubic feet)	(Minutes)	(Minutes)
5	0.64	0.81
10	.64	.82
20	.66	.83
50	.70	.88
100	.78	.95
200	.93	1.11
300	1.08	1.26

d. Unhooking time, relog yarding,

No significant gain through regression; therefore, a simple mean was used of 0.8289 minute per turn for hot-loading settings and 1.177 minutes per turn for cold-decked settings.

e. Loading time, regular yarding,

No significant gain through regression; therefore, a simple mean was used of 0.7409 minute per log.

f. Loading time, relog yarding,

No significant gain through regression; therefore, a simple mean was used of 0.8539 minute per log for hot loading and 1.017 minutes per log for loading from cold deck.

---

[3] Elements S, VS, and C failed to accomplish a significant reduction in the variation of Y_1 and were therefore deleted. Negative sign for N factor is interpreted to mean a given turn volume takes more time in one log, for example, than in two or more smaller logs.

[4] Positive sign for N factor is related to the fact that the relogging crew had only one choker setter, and all turn volumes were relatively small.

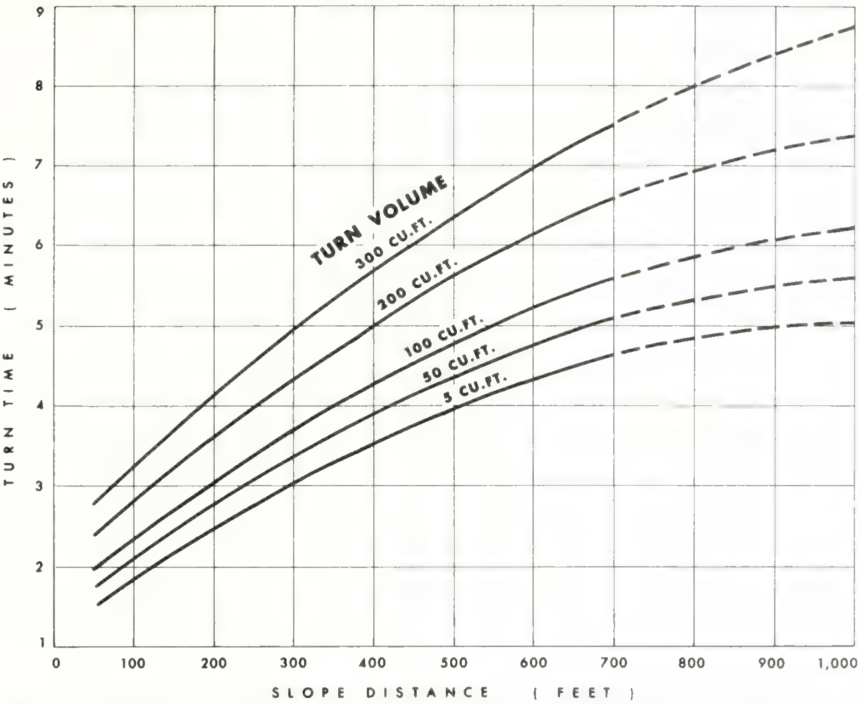


Figure 4.—Round-trip turn time, regular yarding, excluding unhooking time; two logs per turn.

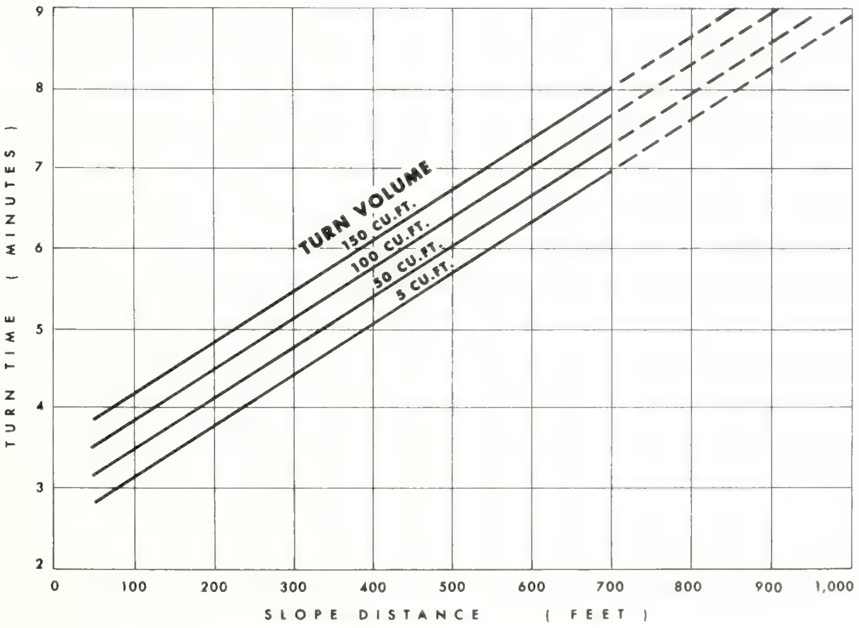


Figure 5.—Round-trip turn time, ~~regular~~ relog yarding, excluding unhooking time; three logs per turn.

Physical Production Rates

Total yarding cycle time per turn (tables 1 and 2[5]) was calculated directly from the results of regression analysis shown in the previous section. This is "marginal time," in the sense that it is the extra time for an extra turn that comes in cleanly without delays. Times for regular logging are for the standard high-lead equipment and a seven-man crew using two chokers, each with a single log. Times for relogging are for the lighter equipment and a five-man crew using three chokers and bringing in three logs per turn.

Loading time for regular logging was assumed to be the same as yarding time, because in normal high-lead operations the loader remains at the landing with the yarder; hence, it requires just as much of the loading machine's time as the yarder's time to handle an extra hour's work or an extra turn.

Since relogging is chiefly to a cold deck, calculated loading time for a relog operation was taken as 1.017 minutes per log, the average time observed.

Hourly Cost Rates

Labor costs and machine rates for yarding and loading are shown in tables 20 and 21. Machine rates are based on 42 weeks or 210 working days per year. An assumption is made that the remaining 10 weeks will be accounted for by holidays, vacation time, moving time between settings, breakdown, and daily or seasonal shutdowns due to bad weather or high fire danger.

Calculation of Unit Costs

Unit costs for the different turn volumes were developed by applying the hourly cost rates for yarding and loading to the physical production rates. In order to relate cost to individual log volume rather than to turn volume, calculations were on the basis of each choker carrying two or three logs of equal volume. In practice, of course, log sizes are mixed in any given turn, and up to the point where working load capacity of the rigging is reached, it should make no difference costwise whether small logs are mixed in with large logs or handled separately.

Costs were initially calculated in units of 100 cubic feet because small log sizes do not have a consistent board-foot to cubic-foot ratio. However, calculated board-foot costs are also shown (Scribner rule).

Yarding costs per turn and per unit volume are given in tables 3-6. Loading costs with regular yarding were related to yarding time because the loading machine normally remains on the landing all through the yarding operation including the extra time required to yard an extra volume of logs (tables 7, 8).

Relog loading was from cold decks and therefore costs were related to loading time per log, which averaged 1.017 minutes. At $0.2155 per minute (derived from table 21), relog loading cost was $0.2192 per log or, expressed in cost per hundred cubic feet, as follows:

Volume per log	Logs per 100 cu. ft.	Loading cost per 100 cu. ft.
(Cubic feet)	(Number)	(Dollars)
2.5	40	8.77
5.0	20	4.38
10.0	10	2.19
25.0	4	.88
50.0	2	.44

---

[5] All tables are contained in the appendixes.

The corresponding relog loading cost per thousand board feet was:

Volume per log	Logs per M bd. ft.	Loading cost per M bd. ft
(Board feet)	(Number)	(Dollars)
10	100	21.92
20	50	10.96
50	20	4.38
100	10	2.19
200	5	1.10

Hauling costs were developed by using tables 8 and 10 of the "Logging Road Handbook" (Byrne et al. 1960)[6], with an adjustment for non-operating season, applying an adjustment factor of 1.12 for price changes since 1959. These costs apply to standard, on-highway, diesel logging trucks. The same hourly costs were used for relogging as for regular logging. Hauling costs were based on 5 miles of single-lane gravel road with 6- to 8-percent grade plus highway mileage to give total hauling distances of 20 to 70 miles. Delay time for scaling, unloading, and waiting at landing was calculated as 35 minutes per trip. Loading time was calculated as 0.74 to 1.0 minute per log, with a maximum of 60 minutes' loading time per load. Resulting hauling costs and related data are shown in tables 9-13.

Totals of direct yarding, loading, and hauling costs per hundred cubic feet are shown in tables 14 and 15. Attention is called to the very wide spread in logging costs, depending on log volume. For example, with a 300-foot yarding distance and 20-mile hauling distance, regular logging costs range from $7.45 to $62.33 per hundred cubic feet for logs 50 to 2.5 cubic feet, respectively, in volume. Corresponding figures for relogging are $6.12 and $41.03 per hundred cubic feet.

Similarly, regular logging costs for the same yarding and hauling distances range from $15.72 to $155.83 per thousand board feet for logs 200 to 10 board feet, respectively. For relogging, the corresponding figures are $12.65 and $102.06 per thousand board feet.

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[6] Name and date in parentheses refers to publication listed in Bibliography, p. 17.

Other Factors affecting Yarding Time and Cost

Effect of Slope

The regression equation showing the greatest addition to explained variance for effect of slope employed the factor VS in the equation for regular logging:

$$Y_i = 1.474 + 0.006989D - 0.000002930D^2 + 0.006938V + 0.00001024DV - 0.0001201VS - 0.1441N$$

Addition of this factor was not statistically significant at the 95-percent confidence level, but was nearly so. For anyone wishing to include the effect of slope, the calculated effect of this factor on turn time and cost per unit volume, compared with yarding on level ground, is:

Slope	Time differential per 100 cu. ft.	Cost differential	
		Per 100 cu. ft.	Per M bd. ft.[1]
(Percent)	(Minutes)	(Dollars)	
Level	0	0	0
10	-0.12	-0.09	-0.16
20	-.24	-.19	-.34
30	-.36	-.28	-.50
40	-.48	-.37	-.67
50	-.60	-.46	-.83
60	-.72	-.56	-1.01

[1] Calculated at 1 cubic foot = 5.556 board feet, or 1,000 board feet = 180 cubic feet.

The following time and cost differential for slope relates to data in the body of this report, which in turn is based on the equation on page 6 and average slope slightly under 30 percent:

Slope	Time differential per 100 cu. ft.	Cost differential	
		Per 100 cu. ft.	Per M bd ft.[1]
(Percent)	(Minutes)	(Dollars)	
Level	+0.32	+0.25	+0.45
10	+.20	+.15	+.29
20	+.8	+.07	+.13
30	-.04	-.02	-.04
40	-.12	-.12	-.22
50	-.28	-.21	-.38
60	-.40	-.30	-.54

[1] Calculated at 1 cubic foot = 5.556 board feet, or 1,000 board feet = 180 cubic feet.

Effect of slope when yarding downhill to the landing was not observed. There was no discernible effect of slope in relog yarding.

Number of Chokers

The chief reason, of course, for using three chokers instead of the customary two is that the yarding equipment can be used more closely to its weight capacity. That is, if the logs in the first two chokers do not make a full load, then the additional log (or logs) in the third choker may be carried at very little extra cost—usually just the extra cost of setting the choker and unhooking.

If the number of chokers is introduced, in addition to the factor VS, the regression equation for regular yarding becomes:

$$Y_i = 1.132 + 0.007123D - 0.000003022D^2 + 0.007870V + 0.000009923DV - 0.0001505VS + 0.1920C - 0.1874N$$

Although addition of this factor did not add significantly to the amount of explained variance in the statistical analysis at the 95-percent confidence level, it has been included for the record.

With the above equation, yarding time and costs were found to be 27 percent less per unit volume if a third choker carried an additional volume the same as each of the other two, and 16 percent less if a third choker carried a load only half as great as the other two.

If the third choker carried a minimum size log, which did not add appreciably to the total load, or if the equivalent two-choker load were carried in three logs and three chokers, then by calculation the logging cost would be $0.17 greater per hundred cubic feet, or $0.31 greater per thousand board feet, than for the same volume in only two chokers. Thus, the economy of using a third choker depends in large measure on the extent a two-choker operation fails to carry a capacity load in each turn.

Economic Analysis

The direct costs of bringing a given log to the mill are the sum of direct yarding, loading, and hauling costs which have been calculated for different yarding distances, hauling distances, and log sizes. Curves of these direct logging costs for a hauling distance of 20 miles are shown in figures 6 and 7. The intersection of these curves with the horizontal line indicating equivalent mill-yard value of purchased wood indicates the marginal log for each method of operation.[7]

Equivalent Mill-Yard Value

Wood from company-owned lands should be preferred so long as its after-tax logging cost is less than the after-tax cost of purchased wood. The equivalent mill-yard value of company wood will include an adjustment for a 27-percent tax saving on any capital gains applicable to the company wood plus an adjustment for a 52-percent tax reduction on logging costs[8]. For example, a price of $18.50 per cord is equivalent to $22.71 per cord after taxes and after capital-gains tax savings, under the assumption of $8 per cord fair market value and $0.50 per cord depletion rate.

Similarly, a buying price of $37 per thousand board feet is equivalent to $45.44 per thousand board feet for company-produced wood, assuming $16 per thousand board feet fair market value and a $1 per thousand board feet depletion rate.

These values are calculated as follows:

	Per cord	Per 100 cubic feet	Per M board feet
a. Cost of purchased wood	$18.50	$20.56	$37.00
Tax reduction (x 0.52)	-9.62	-10.69	-19.24
After-tax cost	8.88	9.87	17.76
b. Equivalent after-tax cost of company wood	8.88	9.87	17.76
Capital-gains tax saving, 0.27(FMV - depletion):			
0.27($8 - $0.50) =	+2.02	-	-
0.27($8.889 - $0.556) =		+2.25	-
0.27($16 - $1) =		- -	+4.05
Equivalent value, before income tax	10.90	12.12	21.81
c. Equivalent mill-yard value (EMYV), at 52-percent income tax:			
EMYV - 0.52 (EMYV) =	10.90	12.12	21.81
EMYV - 0.48 (EMYV) =	10.90	12.12	21.81
EMYV =	22.71	25.25	45.44

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[7] For derivation of cost per log from cost per turn, see discussion on p. 8.

[8] The corporate income tax rate was 52 percent prior to January 1, 1964. This rate was changed to 50 percent from January 1, 1964, and to 48 percent after January 1, 1965. Calculations are shown at the 52-percent rate.

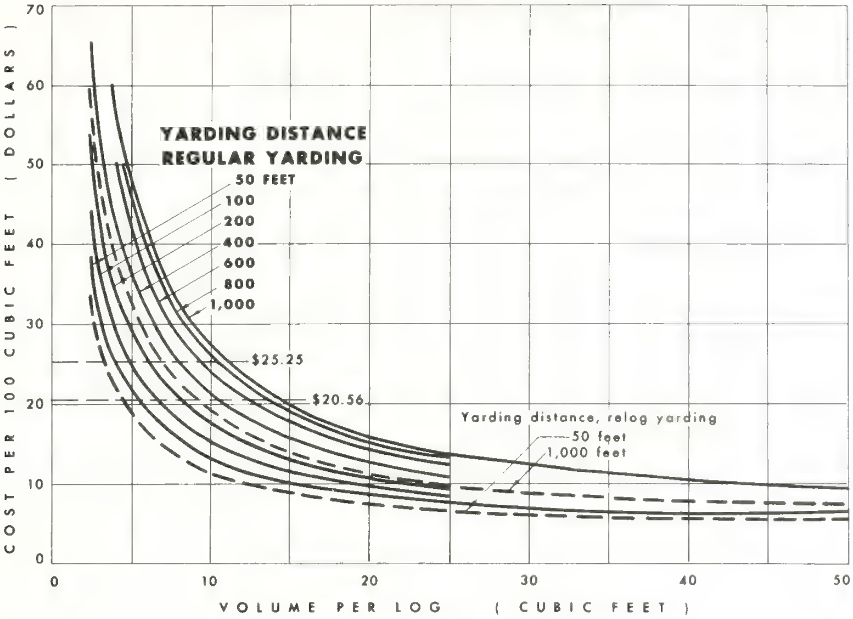

Figure 6.—Total direct logging cost per hundred cubic feet (yarding, loading, hauling). Hauling distance 20 miles.

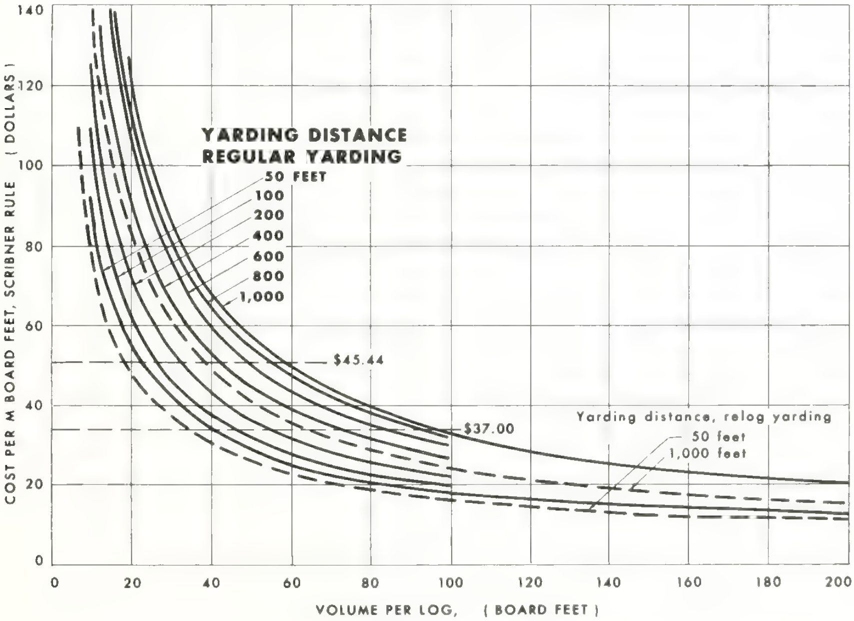

Figure 7.—Total direct logging cost per thousand board feet (yarding, loading, hauling). Hauling distance 20 miles.

The Conversion Surplus

The difference between equivalent mill-yard value and the direct logging costs may be termed the "conversion surplus." Note that fixed costs are excluded from this concept. It will be profitable to bring in any log that has a positive conversion surplus, even though fixed costs are not fully covered, because that log will cover out-of-pocket costs and will make at least some contribution toward meeting fixed costs.

The analysis of this study has been built around a situation where an industrial firm logs its own timber for which there is no direct stumpage charge. The method is valid, however, for any operator. If there is a stumpage charge based on scaled recovery, then the operator will normally view this stumpage charge as an addition to direct costs.[9] On the other hand, if the stumpage is purchased for a lump sum or on a tree-measurement basis, then there is no direct stumpage charge, and this method of analysis is directly applicable.

Whether or not stumpage price is considered as a direct cost, it is clear that the delivered value of each log should at least cover its own direct logging costs.

For an independent logging operator having no mill of his own, the capital-gains tax saving would not apply, and the comparison should be made with the available after-tax market price, taking into account the particular income tax rate for the operator in question.

Marginal Log Sizes

Marginal log sizes according to the costs and price assumptions of this study may be determined by inspection from figures 8 and 9, and are shown in tables 18 and 19 for hauling distances of 20, 40, and 60 miles. Different marginal log sizes would result from different costs and price assumptions. The calculated marginal log sizes do not apply to bonus logs, i.e., those which may be simultaneously set in the same choker with another log. Small logs below the full economic margin may also be taken where no other logs are available to complete a load or where any other available log would overload the machine or rigging. In this case, the economic margin would be determined by the extra cost of setting the extra choker, unhooking, loading, and hauling.

Under observed conditions of this study, any logs smaller than the marginal log size do not pay their way out of the woods. As long as there is an alternative source of raw material for existing mill capacity, any removal of such material can be justified only by silvicultural, protective, or other reasons. Economic justification can only be accomplished by development of more efficient logging and milling methods, use of shorter average yarding distances, or by development of higher log values.

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[9] However, this viewpoint may not be entirely valid if only logs with a positive conversion surplus have been included in the sale, with a single average price charged within species as a practical working arrangement. Neither should this viewpoint be valid if any extra cost of individual small logs, removal of which may be required for silvicultural reasons, is spread among all logs of that species by reducing their total average stumpage value.

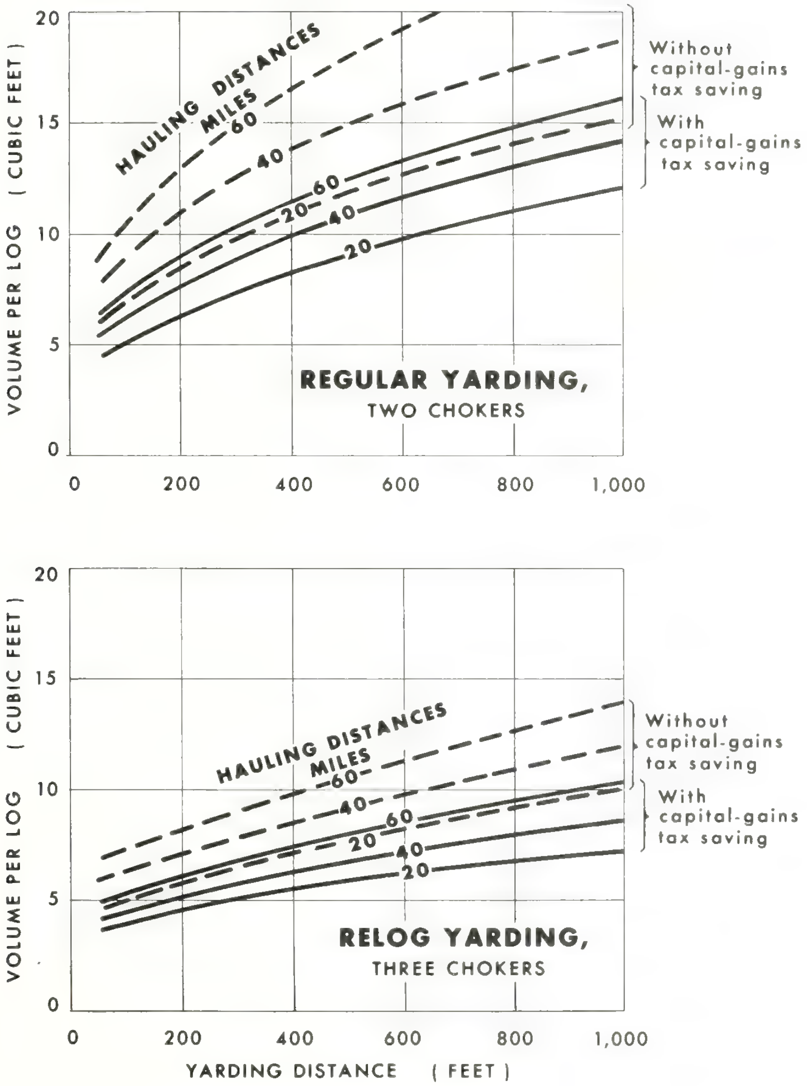

Figure 8.—Marginal log sizes (cubic feet), related to hauling distance, and based on log prices and equivalent mill-yard values described in text.

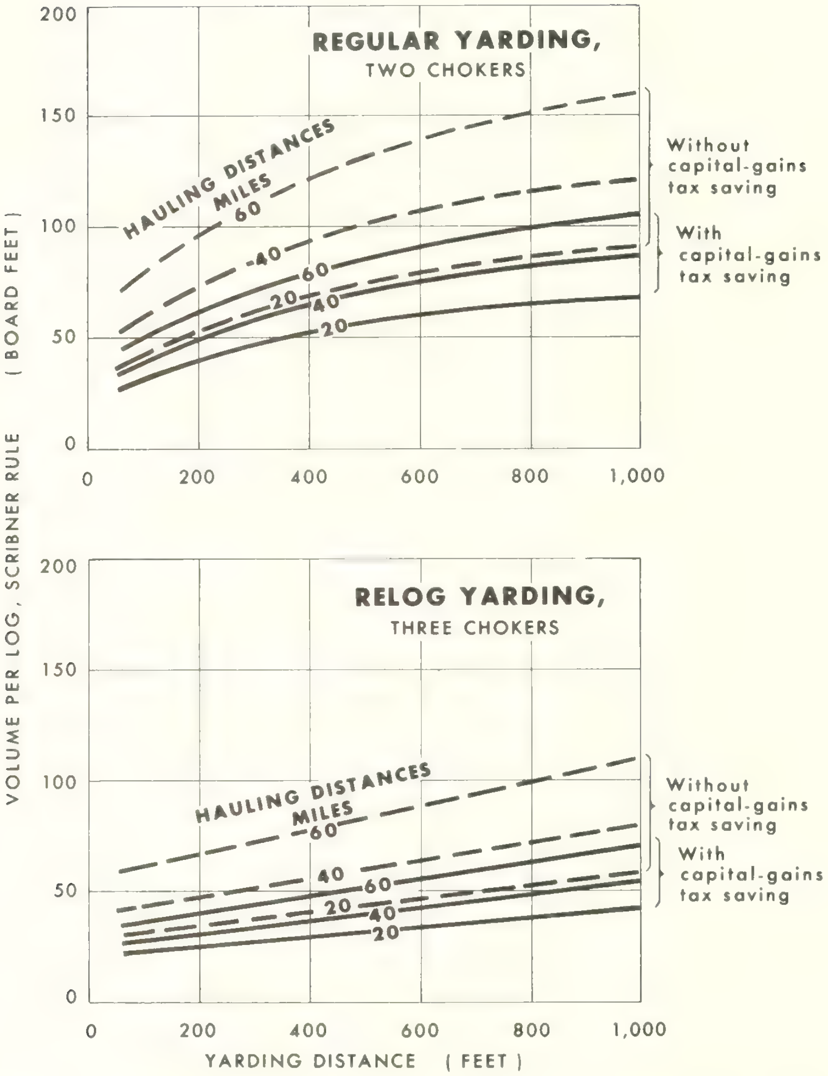

Figure 9.—Marginal log sizes (board feet), related to hauling distance, and based on log prices and equivalent mill-yard values described in text.

Interpretation of Results

Identification of marginal log size is of interest, particularly in a limited supply situation where an operator wishes to maximize the logging returns from a given area. Actually, when a firm owns both forest land and manufacturing plant, it might be advantageous to bring in additional wood below the margin, if this would produce profits in manufacturing that otherwise would not be possible, or if the firm's management decided closer utilization gave flexibility, kept control of wood supply, gave research and development experience for the future, or contributed toward a cleaner setting and a favorable public reaction.

On the other hand, although a general recommendation would be to utilize down to the marginal log wherever possible, there is no magic in earning just enough to cover costs. A case might be made for stopping a little short of the margin; that is, there is no logic in earning just pennies or just breaking even if there is an alternative for a firm to earn more with its manpower and capital equipment elsewhere. However, silviculture, protection, and other noneconomic factors will generally indicate a policy of utilization very close to the economic margin. The challenge to foresters for small log utilization continues to be aimed toward developing ways to utilize them efficiently rather than leaving them behind because they do not pay their way.

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Appendix A

Table 1.—Yarding cycle time in high-lead operations near Cosmopolis, Wash., 1961, by turn volume and slope distance (regular yarding)[1]

Turn volume	Slope distance (feet)										
	50	100	200	300	400	500	600	700	800	900	1,000
	Minutes per turn										
Cubic feet:											
5	2.20	2.54	3.17	3.72	4.21	4.63	4.98	5.26	5.47	5.61	5.68
10	2.23	2.57	3.20	3.76	4.25	4.67	5.02	5.31	5.52	5.67	5.74
20	2.29	2.63	3.27	3.84	4.34	4.77	5.13	5.42	5.65	5.80	5.89
50	2.45	2.81	3.48	4.07	4.50	5.05	5.44	5.76	6.01	6.19	6.30
100	2.74	3.12	3.83	4.47	5.04	5.54	5.97	6.33	6.62	6.85	6.98
200	3.31	3.74	4.53	5.25	5.91	6.49	7.01	7.46	7.84	8.15	8.39
300	3.88	4.35	5.23	6.04	6.78	7.45	8.06	8.59	9.06	9.45	9.78
Board feet (Scribner rule):											
20	2.20	2.54	3.17	3.72	4.21	4.63	4.98	5.26	5.47	5.61	5.68
40	2.23	2.57	3.20	3.76	4.25	4.67	5.02	5.31	5.52	5.67	5.74
100	2.32	2.67	3.30	3.88	4.38	4.82	5.18	5.48	5.71	5.87	5.96
200	2.41	2.78	3.43	4.02	4.54	4.99	5.38	5.69	5.93	6.11	6.21
400	2.60	2.96	3.65	4.26	4.81	5.29	5.70	6.04	6.30	6.51	6.64
1,000	3.16	3.57	4.34	5.04	5.67	6.22	6.73	7.15	7.51	7.79	8.01
2,000	3.96	4.43	5.32	6.14	6.90	7.58	8.19	8.74	9.22	9.62	9.96

[1] Sum of round-trip yarding time and unhooking time. Excludes delay time. Calculated for two chokers and two logs per turn.

Table 2.—Yarding cycle time in high-lead operations near Cosmopolis, Wash., 1961, by turn volume and slope distance (relog yarding)[1]

Turn volume	Slope distance (feet)										
	50	100	200	300	400	500	600	700	800	900	1,000
	Minutes per turn										
Cubic feet:											
5	3.99	4.31	4.95	5.59	6.24	6.88	7.52	8.16	8.81	9.45	10.09
7.5	4.01	4.33	4.97	5.62	6.26	6.90	7.54	8.19	8.82	9.46	10.11
10	4.02	4.35	4.99	5.63	6.27	6.92	7.56	8.20	8.84	9.48	10.13
15	4.06	4.38	5.02	5.67	6.31	6.95	7.60	8.24	8.88	9.52	10.16
20	4.10	4.42	5.06	5.70	6.35	6.99	7.63	8.27	8.92	9.56	10.20
30	4.17	4.49	5.14	5.78	6.42	7.06	7.70	8.35	8.99	9.63	10.27
50	4.32	4.64	5.28	5.92	6.56	7.21	7.85	8.49	9.13	9.78	10.42
75	4.50	4.82	5.46	6.10	6.75	7.39	8.03	8.67	9.32	9.96	10.60
100	4.68	5.00	5.64	6.29	6.93	7.57	8.22	8.86	9.50	10.14	10.78
150	5.05	5.38	6.01	6.65	7.30	7.94	8.58	9.22	9.86	10.51	11.15
Board feet (Scribner rule):											
20	3.99	4.31	4.95	5.59	6.24	6.88	7.52	8.16	8.81	9.45	10.09
30	4.01	4.33	4.97	5.62	6.26	6.90	7.54	8.19	8.82	9.46	10.11
40	4.02	4.35	4.99	5.63	6.27	6.92	7.56	8.20	8.84	9.48	10.13
60	4.06	4.38	5.02	5.67	6.31	6.95	7.60	8.24	8.88	9.52	10.16
100	4.13	4.45	5.10	5.74	6.38	7.02	7.66	8.31	8.95	9.59	10.23
150	4.22	4.54	5.19	5.81	6.47	7.11	7.76	8.40	9.04	9.68	10.33
200	4.27	4.59	5.23	5.87	6.52	7.16	7.80	8.44	9.08	9.73	10.37
300	4.42	4.75	5.39	6.03	6.67	7.32	7.96	8.60	9.24	9.88	10.53
400	4.48	4.80	5.45	6.09	6.73	7.37	8.02	8.66	9.30	9.94	10.59
600	4.76	5.08	5.72	6.37	7.01	7.65	8.29	8.94	9.58	10.22	10.86

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[1] Sum of round-trip yarding time and unhooking time. Excludes delay time. Calculated for three chokers and three logs per turn, yarding to cold deck.

Table 3.—Yarding cost per turn in high-lead operations near Cosmopolis, Wash., 1961, by turn volume and slope distance (regular yarding)[1]

Turn volume	Slope distance (feet)										
	50	100	200	300	400	500	600	700	800	900	1,000
	Dollars per turn										
Cubic feet:											
5	1.12	1.29	1.62	1.90	2.15	2.36	2.54	2.68	2.79	2.86	2.90
10	1.14	1.31	1.63	1.92	2.17	2.38	2.56	2.71	2.81	2.89	2.93
20	1.17	1.34	1.67	1.96	2.21	2.43	2.61	2.76	2.88	2.96	3.00
50	1.25	1.43	1.77	2.07	2.29	2.57	2.77	2.94	3.06	3.16	3.21
100	1.40	1.59	1.95	2.28	2.57	2.82	3.04	3.23	3.37	3.49	3.56
200	1.69	1.91	2.31	2.68	3.01	3.31	3.57	3.80	4.00	4.15	4.28
300	1.98	2.22	2.67	3.08	3.46	3.80	4.11	4.38	4.62	4.82	4.98
Board feet (Scribner rule)											
20	1.12	1.29	1.62	1.90	2.15	2.36	2.54	2.68	2.79	2.86	2.90
40	1.14	1.31	1.63	1.92	2.17	2.38	2.56	2.71	2.81	2.89	2.93
100	1.18	1.36	1.68	1.98	2.23	2.46	2.64	2.79	2.91	2.99	3.04
200	1.23	1.42	1.75	2.05	2.31	2.54	2.74	2.90	3.02	3.11	3.17
400	1.33	1.51	1.86	2.17	2.45	2.70	2.91	3.08	3.21	3.32	3.38
1,000	1.61	1.82	2.21	2.57	2.89	3.17	3.43	3.64	3.83	3.97	4.08
2,000	2.02	2.26	2.71	3.13	3.52	3.86	4.17	4.45	4.70	4.90	5.08

Source: Times of table 1 multiplied by $0.5097 per minute, derived from table 20.

[1] Based on two logs per turn.

Table 4.—Yarding cost per unit volume in high-lead operations near Cosmopolis, Wash., 1961, by log and turn volumes and slope distance (regular yarding)[1]

Log volume	Turn volume	Slope distance (feet)										
		50	100	200	300	400	500	600	700	800	900	1,000
Cubic feet		Dollars per 100 cubic feet										
2.5	5	22.40	25.80	32.40	38.00	43.00	47.20	50.80	53.60	55.80	57.20	58.00
5	10	11.40	13.10	16.30	19.20	21.70	23.80	25.60	27.10	28.10	28.90	29.30
10	20	5.85	6.70	8.35	9.80	11.05	12.15	13.05	13.80	14.40	14.80	15.00
25	50	2.50	2.86	3.54	4.14	4.58	5.14	5.54	5.88	6.12	6.32	6.42
50	100	1.40	1.59	1.95	2.28	2.57	2.82	3.04	3.23	3.37	3.49	3.56
100	200	.84	.96	1.16	1.34	1.50	1.66	1.78	1.90	2.00	2.08	2.14
150	300	.66	.74	.89	1.03	1.15	1.27	1.37	1.46	1.54	1.61	1.66
Board feet[2]		Dollars per M board feet										
10	20	56.00	64.50	81.00	95.00	107.50	118.00	127.00	134.00	139.50	143.00	145.00
20	40	28.50	32.75	40.75	48.00	54.25	59.50	64.00	67.75	70.25	72.25	73.25
50	100	11.80	13.60	16.80	19.80	22.30	24.60	26.40	27.90	29.10	29.90	30.40
100	200	6.15	7.10	8.75	10.25	11.55	12.70	13.70	14.50	15.10	15.55	15.85
200	400	3.32	3.78	4.65	5.43	6.13	6.75	7.28	7.70	8.03	8.30	8.45
500	1,000	1.61	1.82	2.21	2.57	2.89	3.17	3.43	3.64	3.83	3.97	4.08
1,000	2,000	1.01	1.13	1.36	1.57	1.76	1.93	2.09	2.23	2.35	2.45	2.54

Source: Values of table 3 multiplied by number of turns per unit volume.

[1] Based on two logs per turn.

[2] Scribner rule.

Table 5.—Yarding cost per turn in high-lead operations near Cosmopolis, Wash., 1961, by turn volume and slope distance (relog yarding)[1]

Turn volume	Slope distance (feet)										
	50	100	200	300	400	500	600	700	800	900	1,000
	Dollars per turn										
Cubic feet:											
7.5	1.48	1.60	1.83	2.07	2.31	2.54	2.78	3.02	3.25	3.49	3.73
15	1.50	1.61	1.85	2.09	2.33	2.56	2.80	3.04	3.27	3.51	3.74
30	1.54	1.65	1.89	2.13	2.37	2.60	2.84	3.08	3.31	3.55	3.78
75	1.66	1.78	2.01	2.25	2.49	2.72	2.96	3.19	3.43	3.67	3.91
150	1.86	1.98	2.21	2.45	2.69	2.93	3.16	3.40	3.63	3.87	4.11
Board feet (Scribner rule):											
30	1.48	1.60	1.83	2.07	2.31	2.54	2.78	3.02	3.25	3.49	3.73
60	1.50	1.61	1.85	2.09	2.33	2.56	2.80	3.04	3.27	3.51	3.74
150	1.56	1.67	1.91	2.14	2.38	2.62	2.86	3.10	3.33	3.57	3.81
300	1.63	1.75	1.99	2.22	2.46	2.70	2.93	3.17	3.40	3.64	3.88
600	1.75	1.87	2.11	2.35	2.58	2.82	3.05	3.29	3.53	3.77	4.00

Source: Times of table 2 multiplied by $0.3685 per minute, derived from table 20.

[1] Based on three logs per turn.

Table 6.—Yarding cost per unit volume in high-lead operations near Cosmopolis, Wash., 1961, by log and turn volumes and slope distance (relog yarding)[1]

Log volume	Turn volume	Slope distance (feet)										
		50	100	200	300	400	500	600	700	800	900	1,000
Cubic feet		Dollars per 100 cubic feet										
2.5	7.5	19.68	21.28	24.34	27.53	30.72	33.78	36.97	40.17	43.23	46.42	49.61
5	15	10.00	10.74	12.34	13.94	15.54	17.08	18.68	20.28	21.82	23.41	24.95
10	30	5.13	5.49	6.29	7.09	7.86	8.66	9.46	10.26	11.02	11.82	12.59
25	75	2.21	2.37	2.67	2.99	3.31	3.62	3.94	4.24	4.56	4.88	5.20
50	150	1.24	1.32	1.47	1.63	1.79	1.95	2.11	2.27	2.42	2.58	2.74
Board feet[2]		Dollars per M board feet										
10	30	48.84	52.80	60.39	68.31	76.23	83.82	91.74	99.66	107.25	115.17	123.09
20	60	25.05	26.89	30.90	34.90	38.91	42.75	46.76	50.77	54.61	58.62	62.46
50	150	10.45	11.19	12.80	14.34	15.95	17.55	19.16	20.77	22.31	23.92	25.53
100	300	5.38	5.78	6.57	7.33	8.12	8.91	9.67	10.46	11.22	12.01	12.80
200	600	2.92	3.12	3.52	3.92	4.31	4.71	5.09	5.49	5.90	6.30	6.68

Source: Values of table 5 multiplied by number of turns per unit volume.

[1] Based on three logs per turn.

[2] Scribner rule.

Table 7.—Loading cost per turn in high-lead operations near Cosmopolis, Wash., 1961, by turn volume and slope distance (regular yarding)

Turn volume	Slope distance (feet)										
	50	100	200	300	400	500	600	700	800	900	1,000
	Dollars per turn										
Cubic feet:											
5	0.58	0.67	0.83	0.98	1.11	1.22	1.31	1.38	1.44	1.47	1.49
10	.59	.67	.84	.99	1.12	1.23	1.32	1.39	1.45	1.49	1.51
20	.60	.69	.86	1.01	1.14	1.25	1.35	1.42	1.48	1.52	1.55
50	.64	.74	.91	1.07	1.18	1.33	1.43	1.51	1.58	1.63	1.66
100	.72	.82	1.01	1.17	1.32	1.46	1.57	1.66	1.74	1.80	1.83
200	.87	.98	1.19	1.38	1.55	1.70	1.84	1.96	2.06	2.14	2.20
300	1.02	1.14	1.37	1.59	1.78	1.96	2.12	2.26	2.38	2.48	2.57
Board feet (Scribner rule):											
20	.58	.67	.83	.98	1.11	1.22	1.31	1.38	1.44	1.47	1.49
40	.59	.68	.84	.99	1.12	1.23	1.32	1.39	1.45	1.49	1.51
100	.61	.70	.87	1.02	1.15	1.27	1.36	1.44	1.50	1.54	1.57
200	.63	.73	.90	1.06	1.19	1.31	1.41	1.49	1.56	1.61	1.63
400	.68	.78	.96	1.12	1.26	1.39	1.50	1.59	1.66	1.71	1.74
1,000	.83	.94	1.14	1.32	1.49	1.63	1.77	1.88	1.97	2.05	2.10
2,000	1.04	1.16	1.40	1.61	1.81	1.99	2.15	2.30	2.42	2.53	2.62

Source: Yarding times of table 1 multiplied by $0.2627 per minute, derived from table 21.

Table 8.—Loading cost per unit volume in high-lead operations near Cosmopolis, Wash., 1961, by log and turn volumes and slope distance (regular yarding)

Log volume	Turn volume	Slope distance (feet)										
		50	100	200	300	400	500	600	700	800	900	1,000
Cubic feet		Dollars per 100 cubic feet										
2.5	5	11.60	13.40	16.60	19.60	22.20	24.40	26.20	27.60	28.80	29.40	29.80
5	10	5.90	6.70	8.40	9.90	11.20	12.30	13.20	13.90	14.50	14.90	15.10
10	20	3.00	3.45	4.30	5.05	5.70	6.25	6.75	7.10	7.40	7.60	7.75
25	50	1.28	1.48	1.82	2.14	2.36	2.66	2.86	3.02	3.16	3.26	3.32
50	100	.72	.82	1.01	1.17	1.32	1.46	1.57	1.66	1.74	1.80	1.83
100	200	.44	.49	.60	.69	.78	.85	.92	.98	1.03	1.07	1.10
150	300	.34	.38	.46	.53	.59	.65	.71	.75	.79	.83	.86
Board feet[1]		Dollars per M board feet										
10	20	29.00	33.50	41.50	49.00	55.50	61.00	65.50	69.00	72.00	73.50	74.50
20	40	14.75	17.00	21.00	24.75	28.00	30.75	33.00	34.75	36.25	37.25	37.75
50	100	6.10	7.00	8.70	10.20	11.50	12.70	13.60	14.40	15.00	15.40	15.70
100	200	3.15	3.65	4.50	5.30	5.95	6.55	7.05	7.45	7.80	8.05	8.15
200	400	1.70	1.95	2.40	2.80	3.15	3.48	3.75	3.98	4.15	4.28	4.35
500	1,000	.83	.94	1.14	1.32	1.49	1.63	1.77	1.88	1.97	2.05	2.10
1,000	2,000	.52	.58	.70	.81	.91	1.00	1.08	1.15	1.21	1.27	1.31

Source: Values of table 7 multiplied by number of turns per unit volume.

[1] Scribner rule.

Table 9.—Basic hauling cost per trip in high-lead operations near Cosmopolis, Wash., 1961

Distance		Road type[1]	Time per round-trip mile	Travel time	Cumulative travel time	Cumulative operating cost[2]	Cumulative tire cost[3]	Federal-State highway use tax[4]	Delay cost[5]	Adjustment for non-operating season[6]	Total basic cost	Adjusted basic hauling cost[7]
Sectional	Cumulative											
Miles	Miles		Minutes	Minutes	Minutes							
0.5	0.5	G1	6.33	3.2	3.2	$0.67	$0.05	—	$3.11	$0.27	$4.10	$4.59
4.5	5.0	G2	5.01	22.5	25.7	5.37	.47	—	3.11	.43	9.38	10.51
5.0	10.0	P1	3.65	18.2	43.9	9.18	.62	$0.51	3.11	.56	13.98	15.66
10.0	20.0	P1	3.65	36.5	80.4	16.80	.94	1.52	3.11	.82	23.19	25.97
10.0	30.0	P2	3.33	33.3	113.7	23.76	1.24	2.54	3.11	1.06	31.71	35.52
10.0	40.0	P3	3.18	31.8	145.5	30.41	1.56	3.55	3.11	1.28	39.91	44.70
10.0	50.0	P3	3.18	31.8	177.3	37.06	1.86	4.56	3.11	1.51	48.10	53.87
10.0	60.0	P3	3.18	31.8	209.1	43.70	2.18	5.58	3.11	1.73	56.30	63.06
10.0	70.0	P3	3.18	31.8	240.9	50.35	2.48	6.59	3.11	1.96	64.49	72.23

[1] Road types:

G1	Gravel, single lane, 8-percent slope	P1	Paved highway, 4-percent slope
G2	Gravel, 1½ lane, 6-percent slope	P2	Paved highway, 3-percent slope
		P3	Paved highway, 2-percent slope

[2] Operating cost = $0.2090 per minute ($0.0298 fixed cost + $0.1202 operating cost + $0.0590 labor cost); excludes tire cost.

[3] Tire cost = $0.094 per mile on gravel road, $0.0310 per mile on paved road.

[4] Federal-State highway use tax taken as $0.1014 per mile.

[5] Delay cost = $0.0888 per minute for average of 35 minutes for scaling, waiting at landing, etc., or $3.11 per trip.

[6] Cost adjustment for nonoperating season derived from Logging Road Handbook (Byrne et al. 1960).

[7] Based on adjustment factor of 1.12 for price changes 1959-61.

Table 10.—Supplemental hauling cost per load in high-lead operations near Cosmopolis, Wash., 1961[1]

Log volume	Ratio: bd. ft./cu. ft.	Volume per load	Logs per load	Time per load[2]		Supplemental hauling cost per load	
				Regular logging	Relogging	Regular logging	Relogging
		Feet	Number	Minutes	Minutes	Dollars	Dollars
Cubic feet:							
2.5	--	675	270	[3]60	[3]60	5.97	5.97
5	--	675	135	[3]60	[3]60	5.97	5.97
10	--	675	68	50	[3]60	4.98	5.97
25	--	675	27	20	27	1.99	2.69
50	--	675	14	10	14	1.00	1.39
100	--	675	6.8	5	--	.50	--
150	--	675	4.5	[4]4.5	--	.45	--
Board feet, Scribner rule:							
10	4.0	2,700	270	[3]60	[3]60	5.97	5.97
20	4.0	2,700	135	[3]60	[3]60	5.97	5.97
50	4.0	2,700	54	40	55	3.98	5.47
100	4.6	3,100	31	23	32	2.29	3.18
200	5.4	3,640	18	13	18	1.29	1.79
500	5.8	3,920	7.8	5.8	--	.58	
1,000	6.4	4,320	4.3	3.2	--	.32	--
1,500	6.8	4,590	3.1	[4]2.3	--	.23	--

[1] Supplemental hauling cost is the cost of truck and driver during loading time ($0.0995 per minute).

[2] At 0.74 minute per piece for regular logging, 1.02 minutes per piece for relog from cold deck.

[3] Maximum time per load taken as 60 minutes due to use of sled or other bunching arrangement for small logs.

[4] At 1.0 minute per piece.

Table 11.—Total hauling costs, related to cubic-foot log volumes, in high-lead operations near Cosmopolis, Wash., 1961 (regular logging)

Cost basis and hauling distance (miles)	For log volumes (cubic feet) of —						
	2.5	5	10	25	50	100	150
	Dollars						
A. Per trip:							
10	21.63	21.63	20.64	17.65	16.66	16.16	16.11
20	31.94	31.94	30.95	27.96	26.97	26.47	26.42
30	41.49	41.49	40.50	37.51	36.52	36.02	35.97
40	50.67	50.67	49.68	46.69	45.70	45.20	45.15
50	59.84	59.84	58.85	55.86	54.86	54.37	54.32
60	69.03	69.03	68.04	65.05	64.06	63.56	63.51
70	78.20	78.20	77.21	74.22	73.23	72.73	72.68
B. Per 100 cubic feet:							
10	3.20	3.20	3.06	2.61	2.47	2.39	2.39
20	4.73	4.73	4.59	4.14	4.00	3.92	3.91
30	6.15	6.15	6.00	5.56	5.41	5.34	5.33
40	7.51	7.51	7.36	6.92	6.77	6.70	6.69
50	8.87	8.87	8.72	8.28	8.13	8.05	8.05
60	10.23	10.23	10.08	9.64	9.49	9.42	9.41
70	11.59	11.59	11.44	11.00	10.85	10.77	10.77

Source: A, sum of tables 9 and 10. B, data of part A divided by 675 cubic feet per load.

Table 12.—Total hauling costs, related to board foot log volumes, in high-lead operations near Cosmopolis, Wash., 1961 (regular logging)

Cost basis and hauling distance (miles)	For log volumes (board feet, Scribner rule) of —						
	10	20	50	100	200	500	1,000
				Dollars			
A. Per trip:							
10	21.63	21.63	19.64	17.95	16.95	16.24	15.98
20	31.94	31.94	29.95	28.26	27.26	26.55	26.29
30	41.49	41.49	39.50	37.81	36.81	36.10	35.84
40	50.67	50.67	48.68	46.99	45.99	45.28	45.02
50	59.84	59.84	57.85	56.16	55.16	54.45	54.19
60	69.03	69.03	67.04	65.35	64.35	63.64	63.38
70	78.20	78.20	76.21	74.52	73.52	72.81	72.55
B. Per M board feet:							
10	8.01	8.01	7.27	5.79	4.66	4.14	3.70
20	11.83	11.83	11.09	9.12	7.49	6.77	6.09
30	15.37	15.37	14.63	12.20	10.11	9.21	8.30
40	18.77	18.77	18.03	15.16	12.63	11.55	10.42
50	22.16	22.16	21.43	18.12	15.15	13.89	12.54
60	25.57	25.57	24.83	21.08	17.68	16.23	14.67
70	28.96	28.96	28.23	24.04	20.20	18.57	16.79

Source: A, sum of tables 9 and 10. B, data of part A divided by board-foot volume per load.

Table 13.—Total hauling costs in high-lead operations near Cosmopolis, Wash., 1961, by log volume and hauling distance (relogging)

Log volume	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars per 100 cubic feet			
Cubic feet:							
2.5	3.20	4.73	6.15	7.51	8.87	10.23	11.59
5	3.20	4.73	6.15	7.51	8.87	10.23	11.59
10	3.20	4.73	6.15	7.51	8.87	10.23	11.59
25	2.72	4.25	5.66	7.02	8.38	9.74	11.10
50	2.53	4.05	5.47	6.83	8.19	9.55	10.91
				Dollars per M board feet			
Board feet (Scribner rule):							
10	8.01	11.83	15.37	18.77	22.16	25.57	28.96
20	8.01	11.83	15.37	18.77	22.16	25.57	28.96
50	7.83	11.64	15.18	18.58	21.98	25.38	28.78
100	6.08	9.40	12.48	15.45	18.40	21.37	24.33
200	4.79	7.63	10.25	12.77	15.29	17.82	20.34

Table 14.—Total direct logging costs per hundred cubic feet in high-lead operations near Cosmopolis, Wash., 1961, by log volume, yarding distance, and hauling distance (regular yarding)[1]

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars			
Log volume, 2.5 cu. ft.:							
50	37.20	38.73	40.15	41.51	42.87	44.23	45.59
100	42.40	43.93	45.35	46.71	48.07	49.43	50.79
200	52.20	53.73	55.15	56.51	57.87	59.23	60.59
300	60.80	62.33	63.75	65.11	66.47	67.83	69.19
400	68.40	69.93	71.35	72.71	74.07	75.43	76.79
500	74.80	76.33	77.75	79.11	80.47	81.83	83.19
600	80.20	81.73	83.15	84.51	85.87	87.23	88.59
700	84.40	85.93	87.35	88.71	90.07	91.43	92.79
800	87.80	89.33	90.75	92.11	93.47	94.83	96.19
900	89.80	91.33	92.75	94.11	95.47	96.83	98.19
1,000	91.00	92.53	93.95	95.31	96.67	98.03	99.39
Log volume, 5 cu. ft.:							
50	20.50	22.03	23.45	24.81	26.17	27.53	28.89
100	23.00	24.53	25.95	27.31	28.67	30.03	31.39
200	27.90	29.43	30.85	32.21	33.57	34.93	36.29
300	32.30	33.83	35.25	36.61	37.97	39.33	40.69
400	36.10	37.63	39.05	40.41	41.77	43.13	44.49
500	39.30	40.83	42.25	43.61	44.97	46.33	47.69
600	42.00	43.53	44.95	46.31	47.67	49.03	50.39
700	44.20	45.73	47.15	48.51	49.87	51.23	52.59
800	45.80	47.33	48.75	50.11	51.47	52.83	54.19
900	47.00	48.53	49.95	51.31	52.67	54.03	55.39
1,000	47.60	49.13	50.55	51.91	53.27	54.63	55.99

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars			
Log volume, 50 cu. ft.:							
50	4.59	6.12	7.53	8.89	10.25	11.61	12.97
100	4.88	6.41	7.82	9.18	10.54	11.90	13.26
200	5.43	6.96	8.37	9.73	11.09	12.45	13.81
300	5.92	7.45	8.86	10.22	11.58	12.94	14.30
400	6.36	7.89	9.30	10.66	12.02	13.38	14.74
500	6.75	8.28	9.69	11.05	12.41	13.77	15.13
600	7.08	8.61	10.02	11.38	12.74	14.10	15.46
700	7.36	8.89	10.30	11.66	13.02	14.38	15.74
800	7.58	9.11	10.52	11.88	13.24	14.60	15.96
900	7.76	9.29	10.70	12.06	13.42	14.78	16.14
1,000	7.86	9.39	10.80	12.16	13.52	14.88	16.24
Log volume, 100 cu. ft.:							
50	3.67	5.20	6.62	7.98	9.33	10.70	12.05
100	3.84	5.37	6.79	8.15	9.50	10.87	12.22
200	4.15	5.68	7.10	8.46	9.81	11.18	12.53
300	4.42	5.95	7.37	8.73	10.08	11.45	12.80
400	4.67	6.20	7.62	8.98	10.33	11.70	13.05
500	4.90	6.43	7.85	9.21	10.56	11.93	13.28
600	5.09	6.62	8.04	9.40	10.75	12.12	13.47
700	5.27	6.80	8.22	9.58	10.93	12.30	13.65
800	5.42	6.95	8.37	9.73	11.08	12.45	13.80
900	5.54	7.07	8.49	9.85	11.20	12.57	13.92
1,000	5.63	7.16	8.58	9.94	11.29	12.66	14.01

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars			
Log volume, 10 cu. ft.:							
50	11.91	13.44	14.85	16.21	17.57	18.93	20.29
100	13.21	14.74	16.15	17.51	18.87	20.23	21.59
200	15.71	17.24	18.65	20.01	21.37	22.73	24.09
300	17.91	19.44	20.85	22.21	23.57	24.93	26.29
400	19.81	21.34	22.75	24.11	25.47	26.83	28.19
500	21.46	22.99	24.40	25.76	27.12	28.48	29.84
600	22.86	24.39	25.80	27.16	28.52	29.88	31.24
700	23.96	25.49	26.90	28.26	29.62	30.98	32.34
800	24.86	26.39	27.80	29.16	30.52	31.88	33.24
900	25.46	26.99	28.40	29.76	31.12	32.48	33.84
1,000	25.81	27.34	28.75	30.11	31.47	32.83	34.19
Log volume, 25 cu. ft.:							
50	6.39	7.92	9.34	10.70	12.06	13.42	14.78
100	6.95	8.48	9.90	11.26	12.62	13.98	15.34
200	7.97	9.50	10.92	12.28	13.64	15.00	16.36
300	8.89	10.42	11.84	13.20	14.56	15.92	17.28
400	9.55	11.08	12.50	13.86	15.22	16.58	17.94
500	10.41	11.94	13.36	14.72	16.08	17.44	18.80
600	11.01	12.54	13.96	15.32	16.68	18.04	19.40
700	11.51	13.04	14.46	15.82	17.18	18.54	19.90
800	11.89	13.42	14.84	16.20	17.56	18.92	20.28
900	12.19	13.72	15.14	16.50	17.86	19.22	20.58
1,000	12.35	13.88	15.30	16.66	18.02	19.38	20.74
Log volume, 150 cu. ft.:							
50	3.39	4.91	6.33	7.69	9.05	10.41	11.77
100	3.51	5.03	6.45	7.81	9.17	10.53	11.89
200	3.74	5.26	6.68	8.04	9.40	10.76	12.12
300	3.95	5.47	6.89	8.25	9.61	10.97	12.33
400	4.13	5.65	7.07	8.43	9.79	11.15	12.51
500	4.31	5.83	7.25	8.61	9.97	11.33	12.69
600	4.47	5.99	7.41	8.77	10.13	11.49	12.85
700	4.60	6.12	7.54	8.90	10.26	11.62	12.98
800	4.72	6.24	7.66	9.02	10.38	11.74	13.10
900	4.83	6.35	7.77	9.13	10.49	11.85	13.21
1,000	4.91	6.43	7.85	9.21	10.57	11.93	13.29

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[1] Sum of tables 4, 8, and 11.

Table 15.—Total direct logging costs per hundred cubic feet in high-lead operations near Cosmopolis, Wash., 1961, by log volume, yarding distance, and hauling distance (relogging)[1]

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars			
Log volume, 2.5 cu. ft.:							
50	31.65	33.18	34.60	35.96	37.32	38.68	40.04
100	33.25	34.78	36.20	37.56	38.92	40.28	41.64
200	36.31	37.84	39.26	40.62	41.98	43.34	44.70
300	39.50	41.03	42.45	43.81	45.17	46.53	47.89
400	42.69	44.22	45.64	47.00	48.36	49.72	51.08
500	45.75	47.28	48.70	50.06	51.42	52.78	54.14
600	48.94	50.47	51.89	53.25	54.61	55.97	57.33
700	52.14	53.67	55.09	56.45	57.81	59.17	60.53
800	55.20	56.73	58.15	59.51	60.87	62.23	63.59
900	58.39	59.92	61.34	62.70	64.06	65.37	66.78
1,000	61.58	63.11	64.53	65.89	67.25	68.61	69.97
Log volume, 5 cu. ft.:							
50	17.58	19.11	20.53	21.89	23.25	24.61	25.97
100	18.32	19.85	21.27	22.63	23.99	25.35	26.71
200	19.92	21.45	22.87	24.23	25.59	26.95	28.31
300	21.52	23.05	24.47	25.83	27.19	28.55	29.91
400	23.12	24.65	26.07	27.43	28.79	30.15	31.51
500	24.66	26.19	27.61	28.97	30.33	31.69	33.05
600	26.26	27.79	29.21	30.57	31.93	33.29	34.65
700	27.86	29.39	30.81	32.17	33.53	34.89	36.25
800	29.39	30.92	32.34	33.70	35.06	36.42	37.78
900	30.99	32.52	33.94	35.30	36.66	38.02	39.38
1,000	32.53	34.06	35.48	36.84	38.20	39.56	40.92
Log volume, 10 cu. ft.:							
50	10.52	12.05	13.47	14.83	16.19	17.55	18.91
100	10.88	12.41	13.83	15.19	16.55	17.91	19.27
200	11.68	13.21	14.63	15.99	17.35	18.71	20.07
300	12.48	14.01	15.43	16.79	18.15	19.51	20.87
400	13.25	14.78	16.20	17.56	18.92	20.28	21.64
500	14.05	15.58	17.00	18.35	19.72	21.08	22.44
600	14.85	16.38	17.80	19.16	20.52	21.88	23.24
700	15.65	17.18	18.60	19.96	21.32	22.68	24.04
800	16.41	17.94	19.36	20.72	22.08	23.44	24.80
900	17.21	18.74	20.16	21.52	22.88	24.24	25.60
1,000	17.98	19.51	20.93	22.29	23.65	25.01	26.37
Log volume, 25 cu. ft.:							
50	5.81	7.34	8.75	10.11	11.47	12.83	14.19
100	5.97	7.50	8.91	10.27	11.63	12.99	14.35
200	6.27	7.80	9.21	10.57	11.93	13.29	14.65
300	6.59	8.12	9.53	10.89	12.25	13.61	14.97
400	6.91	8.44	9.85	11.21	12.57	13.93	15.29
500	7.22	8.75	10.16	11.52	12.88	14.24	15.60
600	7.54	9.07	10.48	11.84	13.20	14.56	15.92
700	7.84	9.37	10.78	12.14	13.50	14.86	16.22
800	8.16	9.69	11.10	12.46	13.82	15.18	16.54
900	8.48	10.01	11.42	12.78	14.14	15.50	16.86
1,000	8.80	10.33	11.74	13.10	14.46	15.82	17.18

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars			
Log volume, 50 cu. ft.:							
50	4.21	5.73	7.15	8.51	9.87	11.23	12.59
100	4.29	5.81	7.23	8.59	9.95	11.31	12.67
200	4.44	5.96	7.38	8.74	10.10	11.46	12.82
300	4.60	6.12	7.54	8.90	10.26	11.62	12.98
400	4.76	6.28	7.70	9.06	10.42	11.78	13.14
500	4.92	6.44	7.86	9.22	10.58	11.94	13.30
600	5.08	6.60	8.02	9.38	10.74	12.10	13.46
700	5.24	6.76	8.18	9.54	10.90	12.26	13.62
800	5.39	6.91	8.33	9.69	11.05	12.41	13.77
900	5.55	7.07	8.49	9.85	11.21	12.57	13.93
1,000	5.71	7.23	8.65	10.01	11.37	12.73	14.09

[1] Sum of tables 6, 13, and loading costs in text.

Table 16.—Total direct logging costs per thousand board feet, Scribner rule, in high-lead operations near Cosmopolis, Wash., 1961, by log volume, yarding distance, and hauling distance (regular logging)[1]

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
	Dollars						
Log volume, 10 bd. ft.:							
50	93.01	96.83	100.37	103.77	107.16	110.57	113.96
100	106.01	109.83	113.37	116.77	120.16	123.57	126.96
200	130.51	134.33	137.87	141.27	144.66	148.07	151.46
300	152.01	155.83	159.37	162.77	166.16	169.57	172.96
400	171.01	174.83	178.37	181.77	185.16	188.57	191.96
500	187.01	190.83	194.37	197.77	201.16	204.57	207.96
600	200.51	204.33	207.87	211.27	214.66	218.07	221.46
700	211.01	214.83	218.37	221.77	225.16	228.57	231.96
800	219.51	223.33	226.87	230.27	233.66	237.07	240.46
900	224.51	228.33	231.87	235.27	238.66	242.07	245.46
1,000	227.51	231.33	234.87	238.27	241.66	245.07	248.46
Log volume, 20 bd. ft.:							
50	51.26	55.08	58.62	62.02	65.41	68.82	72.21
100	57.76	61.58	65.12	68.52	71.91	75.32	78.71
200	69.76	73.58	77.12	80.52	83.91	87.32	90.71
300	80.76	84.58	88.12	91.52	94.91	98.32	101.71
400	90.26	94.08	97.62	101.02	104.41	107.82	111.21
500	98.26	102.08	105.62	109.02	112.41	115.82	119.21
600	105.01	108.83	112.37	115.77	119.16	122.57	125.96
700	110.51	114.33	117.87	121.27	124.66	128.07	131.46
800	114.51	118.33	121.87	125.27	128.66	132.07	135.46
900	117.51	121.33	124.87	128.27	131.66	135.07	138.46
1,000	119.01	122.83	126.37	129.77	133.16	136.57	139.96
Log volume, 200 bd. ft.:							
50	9.68	12.51	15.13	17.65	20.17	22.70	25.22
100	10.39	13.22	15.84	18.36	20.88	23.41	25.93
200	11.71	14.54	17.16	19.68	22.20	24.73	27.25
300	12.89	15.72	18.34	20.86	23.38	25.91	28.43
400	13.94	16.77	19.39	21.91	24.43	26.96	29.48
500	14.89	17.72	20.34	22.86	25.38	27.91	30.43
600	15.69	18.52	21.14	23.66	26.18	28.71	31.23
700	16.34	19.17	21.79	24.31	26.83	29.36	31.88
800	16.84	19.67	22.29	24.81	27.33	29.86	32.38
900	17.24	20.07	22.69	25.21	27.73	30.26	32.78
1,000	17.46	20.29	22.91	25.43	27.95	30.48	33.00
Log volume, 500 bd. ft.:							
50	6.58	9.21	11.65	13.99	16.33	18.67	21.01
100	6.90	9.53	11.97	14.31	16.65	18.99	21.33
200	7.49	10.12	12.56	14.90	17.24	19.58	21.92
300	8.03	10.66	13.10	15.44	17.78	20.12	22.46
400	8.52	11.15	13.59	15.93	18.27	20.61	22.95
500	8.94	11.57	14.01	16.35	18.69	21.03	23.37
600	9.34	11.97	14.41	16.75	19.09	21.43	23.77
700	9.66	12.29	14.73	17.07	19.41	21.75	24.09
800	9.94	12.57	15.01	17.35	19.69	22.03	24.37
900	10.16	12.79	15.23	17.57	19.91	22.25	24.59
1,000	10.32	12.95	15.39	17.73	20.07	22.41	24.75

Log volume and yarding distance (feet)	Hauling distance (miles) 10	20	30	40	50	60	70
				Dollars			
Log volume, 50 bd. ft.:							
50	25.17	28.99	32.53	35.93	39.33	42.73	46.13
100	27.87	31.69	35.23	38.63	42.03	45.43	48.83
200	32.77	36.59	40.13	43.53	46.93	50.33	53.73
300	37.27	41.09	44.63	48.03	51.43	54.83	58.23
400	41.07	44.89	48.43	51.83	55.23	58.63	62.03
500	44.57	48.39	51.93	55.33	58.73	62.13	65.53
600	47.27	51.09	54.63	58.03	61.43	64.83	68.23
700	49.57	53.39	56.93	60.33	63.73	67.13	70.53
800	51.37	55.19	58.73	62.13	65.53	68.93	72.33
900	52.57	56.39	59.93	63.33	66.73	70.13	73.53
1,000	53.37	57.19	60.73	64.13	67.53	70.93	74.33
Log volume, 100 bd. ft.:							
50	15.09	18.42	21.50	24.46	27.42	30.38	33.34
100	16.54	19.87	22.95	25.91	28.87	31.83	34.79
200	19.04	22.37	25.45	28.41	31.37	34.33	37.29
300	21.34	24.67	27.75	30.71	33.67	36.63	39.59
400	23.29	26.62	29.70	32.66	35.62	38.58	41.54
500	25.04	28.37	31.45	34.41	37.37	40.33	43.29
600	26.54	29.87	32.95	35.91	38.87	41.83	44.79
700	27.74	31.07	34.15	37.11	40.07	43.03	45.99
800	28.69	32.02	35.10	38.06	41.02	43.98	46.94
900	29.39	32.72	35.80	38.76	41.72	44.68	47.64
1,000	29.79	33.12	36.20	39.16	42.12	45.08	48.04
Log volume, 1,000 bd. ft.:							
50	5.23	7.62	9.83	11.95	14.07	16.20	18.32
100	5.41	7.80	10.01	12.13	14.25	16.38	18.50
200	5.76	8.15	10.36	12.48	14.60	16.73	18.85
300	6.08	8.47	10.68	12.80	14.92	17.05	19.17
400	6.37	8.76	10.97	13.09	15.21	17.34	19.46
500	6.63	9.02	11.23	13.35	15.47	17.60	19.72
600	6.87	9.26	11.47	13.59	15.71	17.84	19.96
700	7.08	9.47	11.68	13.80	15.92	18.05	20.17
800	7.26	9.65	11.86	13.98	16.10	18.23	20.35
900	7.42	9.81	12.02	14.14	16.26	18.39	20.51
1,000	7.55	9.94	12.15	14.27	16.39	18.52	20.64

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[1] Sum of tables 4, 8, and 12.

Table 17.—Total direct logging costs per thousand board beet, Scribner rule, in high-lead operations near Cosmopolis, Wash., 1961, by log volume, yarding distance, and hauling distance ((relogging)[1]

Log volume and yarding distance (feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
				Dollars			
Log volume, 10 bd. ft.:							
50	78.77	82.59	86.13	89.53	92.92	96.33	99.72
100	82.73	86.55	90.09	93.49	96.88	100.29	103.68
200	90.32	94.14	97.68	101.08	104.47	107.88	111.27
300	98.24	102.06	105.60	109.00	112.39	115.80	119.19
400	106.16	109.98	113.52	116.92	120.31	123.72	127.11
500	113.75	117.57	121.11	124.51	127.90	131.31	134.70
600	121.67	125.49	129.03	132.43	135.82	139.23	142.62
700	129.59	133.41	136.95	140.35	143.74	147.15	150.54
800	137.18	141.00	144.54	147.94	151.33	154.74	158.13
900	145.10	148.92	152.46	155.86	159.25	162.66	166.05
1,000	153.02	156.84	160.38	163.78	167.17	170.58	173.97
Log volume, 20 bd. ft.:							
50	44.02	47.84	51.38	54.78	58.17	61.58	64.97
100	45.86	49.68	53.22	56.62	60.01	63.42	66.81
200	49.87	53.69	57.23	60.63	64.02	67.43	70.82
300	53.87	57.69	61.23	64.63	68.02	71.43	74.82
400	57.88	61.70	65.24	68.64	72.03	75.44	78.83
500	61.72	65.54	69.08	72.48	75.87	79.28	82.67
600	65.73	69.55	73.09	76.49	79.88	83.29	86.68
700	69.74	73.56	77.10	80.50	83.89	87.30	90.69
800	73.58	77.40	80.94	84.34	87.73	91.14	94.53
900	77.59	81.41	84.95	88.35	91.74	95.15	98.54
1,000	81.43	85.25	88.79	92.19	95.58	98.99	102.36

Table 18.—Marginal log volumes, cubic feet, in high-lead operations near Cosmopolis, Wash., 1961, by logging method, slope distance, and hauling distance[1]

Logging method and slope distance (feet)	Marginal log with capital-gains tax saving and hauling distance of —			Marginal log without tax saving and hauling distance of —		
	20 miles	40 miles	60 miles	20 miles	40 miles	60 miles
Regular logging:						
50	5	5	6	6	7	9
100	5	6	7	7	9	10
200	7	8	9	8	11	13
300	7	9	10	10	12	15
400	8	10	12	11	14	16
500	9	11	13	12	15	18
600	10	12	13	13	16	19
700	10	12	14	13	17	20
800	11	13	15	14	17	20
900	11	13	15	14	18	21
1,000	12	14	16	15	18	21
Relogging:						
50	4	4	5	5	6	7
100	4	5	5	5	6	7
200	4	5	6	6	7	8
300	5	6	7	6	8	9
400	5	6	7	7	8	10
500	5	7	8	7	9	10
600	6	7	8	8	10	11
700	6	7	9	8	10	12
800	7	8	9	9	11	13
900	7	8	10	9	11	13
1,000	7	9	10	10	12	14

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[1] Based on log prices and equivalent mill-yard values described in text.

100	23.40	27.21	30.75	34.15	37.55	40.95	44.35
200	25.01	28.82	32.36	35.76	39.16	42.56	45.96
300	26.55	30.36	33.90	37.30	40.70	44.10	47.50
400	28.16	31.97	35.51	38.91	42.31	45.71	49.11
500	29.76	33.57	37.11	40.51	43.91	47.31	50.71
600	31.37	35.18	38.72	42.12	45.52	48.92	52.32
700	32.98	36.79	40.33	43.73	47.13	50.53	53.93
800	34.52	38.33	41.87	45.27	48.67	52.07	55.47
900	36.13	39.94	43.48	46.88	50.28	53.68	57.08
1,000	37.74	41.55	45.09	48.49	51.89	55.29	58.69
Log volume, 100 bd. ft.:							
50	13.65	16.97	20.05	23.02	25.97	28.94	31.90
100	14.05	17.37	20.45	23.42	26.37	29.34	32.30
200	14.84	18.16	21.24	24.21	27.16	30.13	33.09
300	15.60	18.92	22.00	24.97	27.92	30.89	33.85
400	16.39	19.71	22.79	25.76	28.71	31.68	34.64
500	17.18	20.50	23.58	26.55	29.50	32.47	35.43
600	17.94	21.26	24.34	27.31	30.26	33.23	36.19
700	18.73	22.05	25.13	28.10	31.05	34.02	36.98
800	19.49	22.81	25.89	28.86	31.81	34.78	37.74
900	20.28	23.60	26.68	29.65	32.60	35.57	38.53
1,000	21.07	24.39	27.47	30.44	33.39	36.36	39.32
Log volume, 200 bd. ft.:							
50	8.81	11.65	14.27	16.79	19.31	21.84	24.36
100	9.01	11.85	14.47	16.99	19.51	22.04	24.56
200	9.41	12.25	14.87	17.39	19.91	22.44	24.96
300	9.81	12.65	15.27	17.79	20.31	22.84	25.36
400	10.20	13.04	15.66	18.18	20.70	23.23	25.75
500	10.60	13.44	16.06	18.58	21.10	23.63	26.15
600	10.98	13.82	16.44	18.96	21.48	24.01	26.53
700	11.38	14.22	16.84	19.36	21.88	24.41	26.93
800	11.79	14.63	17.25	19.77	22.29	24.82	27.34
900	12.19	15.03	17.65	20.17	22.69	25.22	27.74
1,000	12.57	15.41	18.03	20.55	23.07	25.60	28.12

[1] Sum of tables 6, 13, and loading costs in text.

Table 19.—Marginal log volumes, board feet (Scribner rule), in high-lead operations near Cosmopolis, Wash., 1961, by logging method, slope distance, and hauling distance[1]

Logging method and slope distance (feet)	Marginal log with capital-gains tax saving and hauling distance of —			Marginal log without tax saving and hauling distance of —		
	20 miles	40 miles	60 miles	20 miles	40 miles	60 miles
Regular logging:						
50	26	34	46	36	49	68
100	31	40	52	41	55	78
200	39	50	63	50	70	94
300	45	58	73	58	84	110
400	50	65	81	66	92	122
500	55	70	87	72	100	132
600	59	75	92	77	106	140
700	62	79	96	81	110	146
800	64	82	99	85	114	150
900	66	85	102	88	117	155
1,000	68	87	105	90	120	160
Relogging:						
50	22	29	37	30	41	60
100	23	31	39	31	43	62
200	25	33	42	34	47	68
300	28	36	46	37	51	73
400	30	39	50	40	54	78
500	32	41	53	43	58	83
600	35	44	57	46	62	88
700	37	47	60	49	66	94
800	39	50	64	51	69	99
900	42	52	67	54	73	104
1,000	44	55	71	57	76	110

[1] Based on log prices and equivalent mill-yard values described in text.

Table 20.—Summary of yarding costs in high-lead operations near Cosmopolis, Wash., 1961

Item	Regular yarding		Relog yarding	
	Per day	Per hour	Per day	Per hour
	Dollars			
Yarder,[1]				
3-drum crawler unit:				
Depreciation @ 15,000 hours	16.08	--	11.36	--
Interest, 6 percent of average investment	5.26	--	3.71	-
Fuel and lubrication[2]	7.67	--	5.97	--
Repairs, 50 percent of depreciation	8.04	--	5.68	
Taxes, 2 percent of average investment	1.75	--	1.24	--
Insurance, 1 percent of average investment	.88	--	.62	--
Subtotal	39.68	4.96	28.58	3.57
Labor:				
7-man crew	144.08	--	--	--
5-man crew	--	--	104.20	--
Payroll overhead (22 percent)	31.70	--	22.92	--
Crew transportation	15.51	--	11.09	--
Subtotal	191.29	23.91	138.21	17.28
Wire rope:[3]				
1,000 feet, 1-1/8-inch main line	2.89	--	--	--
1,000 feet, 1-inch main line	--		2.33	--
3,000 feet, 5/8-inch haulback	3.20	--	--	--
3,000 feet, 1/2-inch haulback	-	-	3.00	--
3,000 feet, 3/8-inch straw line	.78	-	--	--
3,000 feet, 5/16-inch straw line			.69	--
Straps	.42	--	.42	--
Chokers, 7/8-inch	4.26	.		--
Chokers, 3/4-inch	--	--	1.64	--
Subtotal	11.55	1.44	8.08	1.01
Blocks:				
Butt rigging, shackles, fire tools, fuel tank, sled, signal unit, powersaw	2.09	.26	1.98	.25
Total yarding cost	244.61	30.58	176.85	22.11

[1] Clean logging used 235-horsepower torque converter crawler tractor, estimated delivered price, new = $42,700. Estimated used price (one-third of new) = $14,233 plus 3-drum yarding winch ($19,225) = $33,458 — 10 percent salvage value = $30,112 amount to be depreciated.

Relogging used 125-horsepower crawler tractor, estimated delivered price, new = $30,815. Estimated used price (one-third of new) = $10,272 plus 3-drum yarding winch ($13,350) = $23,622 — 10 percent salvage value = $21,260 amount to be depreciated.

All calculations are based on 210 operating days per year.

[2] Developed from Caterpillar Tractor Co. Performance Handbook.

[3] Estimated life of main and haulback lines is 9 million board feet, or 225 days (1,800 hours) at 40,000 board feet per day. Estimated life of straw line is approximately 2 years (480 days); straps, approximately 1 year (240 days). Estimated life of 7/8-inch chokers, 15 days, and 3/4-inch chokers, 30 days, with salvage of half the ferrules and hooks.

Table 21.—Summary of loading costs in high-lead operations near Cosmopolis, Wash., 1961

Item	Regular yarding (1-yard model)		Relog yarding (3/4-yard model)	
	Per day	Per hour	Per day	Per hour
	Dollars			
Loader,[1]				
rubber-mounted unit with power tongs:				
Depreciation @ 20,000 hours	25.84	--	16.16	--
Interest, 6 percent of average investment	13.83	--	8.64	--
Fuel and lubrication	8.00	--	6.80	--
Repairs, 25 percent of depreciation	6.46	--	4.04	--
Cable replacement, every 20 days	.45	--	.26	--
Taxes, 2 percent of average investment	4.61	--	2.88	--
Tire replacement @ 10,000 hours	2.48	--	1.12	--
Insurance, 1 percent of average investment	2.30	--	1.44	--
Subtotal	63.97	8.00	41.34	5.17
Labor:				
Two men	47.24	--	47.24	--
Payroll overhead (22 percent)	10.39	--	10.39	--
Crew transportation	4.47	--	4.47	--
Subtotal	62.10	7.76	62.10	7.76
Total	126.07	15.76	103.44	12.93

[1] Estimated delivered price, new, for 1-yard model = $53,000 — 20 percent salvage value = $42,400 + fuel tank and radio @ $430 = $42,830 amount to be depreciated.

Price for 3/4-yard model = $32,000 — 20 percent salvage value = $25,600 + fuel tank and radio @ $430 = $26,030 amount to be depreciated.

All calculations based on 210 operating days per year.

Appendix B

Labor and equipment costs have been treated in the main body of this report as direct hourly costs. This is in keeping with the concept that such costs may be varied according to number of hours worked per day (for labor) or to choice of equipment and number of hours or days worked per year (for equipment).[10] This conceptual framework is intended to represent the practical situation where a machine rate is calculated for each piece of equipment to represent its hourly cost, with straight-line depreciation occurring with hourly use and with costs of interest, taxes, and insurance also considered a part of the hourly machine rate.

Under such conditions, the operator will continue to remove smaller material up to the point where he just covers his hourly labor and equipment costs. He has just so many working hours available per year and, normally, he has the alternative of moving on to another setting.

There may be times, however, when a more limited concept of direct costs would be considered, and the analysis may be extended to two more limited situations: (1) maximizing returns per setting, where men and equipment would otherwise be idle, or (2) maximizing returns from all possible settings, from a given set of equipment and crew, where there is always the opportunity to move on to another setting.

Maximizing Returns Per Setting

In the first of these more limited situations, capital equipment costs may be regarded largely as fixed or sunk costs which were incurred when the decision was made to purchase and operate the equipment. Specifically, costs of depreciation, interest, taxes, and insurance are **not** considered here as related to hours worked. This would be the case for extra work in otherwise slack time when the machine would be idle — as might be the case with a loader, for example, committed to remain on the landing for the duration of yarding — or for overtime work. If the loading crew would otherwise be idle, as often occurs between yarding turns or when there is no truck available for loading, then even the wages of these men would not be applicable to their increment of extra work.

Cost of repairs could also be considered as fixed costs, unrelated to a given extra log output. For extra work in overtime periods or in otherwise slack time, there would also be no extra cost for crew transportation, since there would be no extra travel time involved.

Omitting from machine rates the costs of depreciation, interest, taxes, insurance, repairs, and crew transportation, the hourly rates for yarding, loading, and hauling may be calculated as shown in tables 22, 23, and 24. These may be applied to times per turn or per load to give corresponding costs which can then be divided by volume output to give cost per unit volume. Resulting costs are shown graphically in figure 10.

This type of marginal log analysis will minimize losses from sunk costs when there is no alternative use of the equipment (or men). Occasionally such a situation might arise temporarily as, for example, a result of some emergency or poor planning. If this situation persisted, the operator would probably be better off to sell the equipment so as to recover whatever capital value remained and reinvest in more profitable types of equipment or enterprise.

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[10] See Matthews' discussion of unit costs and machine rates (1942, pp. 45-61).

Maximizing Returns from All Possible Settings

In the second limited situation, it may be considered that operations could always be shifted to another setting up to the point where the gain in lower unit operating costs, achieved through leaving more and more of the lower value logs, would be offset by the extra costs of moving, hangups and breakage in yarding through the material to be left, and by the extra costs of developing extra settings.

This method aims at maximizing by equating marginal net revenues from all possible settings over the fixed working life of the equipment. This situation would lead toward maximum high grading, with a given set of equipment and crew. It is difficult to visualize such a situation. As soon as appreciable amounts of small or medium-sized merchantable pieces were left, it would pay to add additional equipment and crew to go in and relog the setting. That is, there would no longer be a fixed amount of equipment and crew from which to try to maximize returns.

The conclusion is that neither of the alternative conditions described in this appendix fits the day-to-day situations faced by most operators, and the marginal analysis described in the main body of this report, which is built around an hourly machine rate that includes capital equipment costs as well as labor and fuel costs, is a more satisfactory framework for determination of marginal log size.

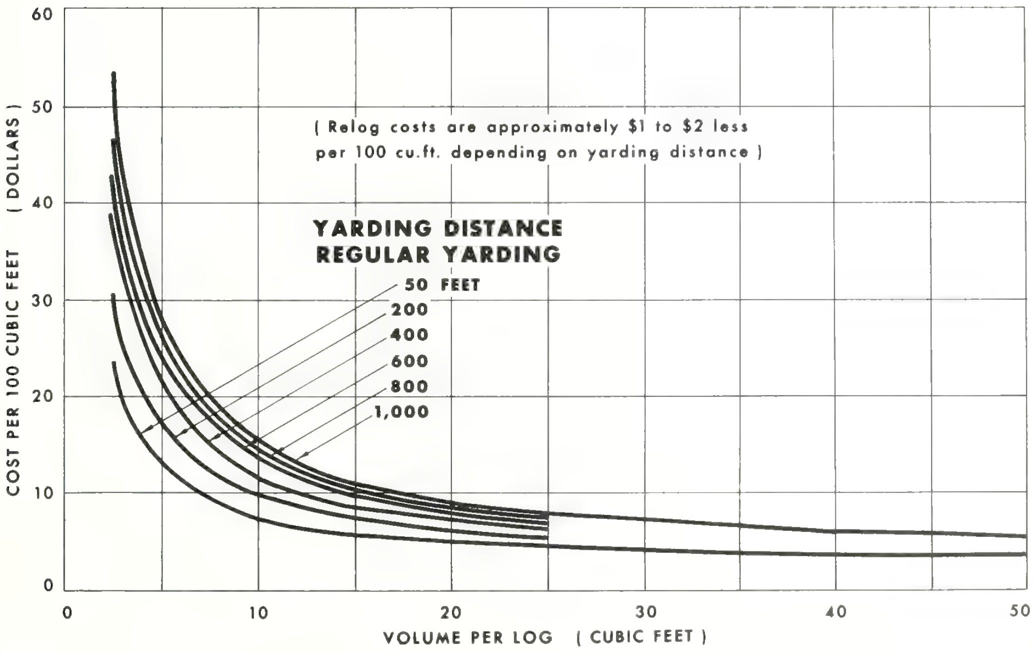

Figure 10.—Direct logging cost per hundred cubic feet (yarding, loading, hauling), excluding depreciation and related items. Hauling distance 20 miles.

Table 22.—Direct yarding costs for fuel and labor in high-lead operations near Cosmopolis, Wash., 1961

Item	Regular yarding		Relog yarding	
	Per day	Per hour	Per day	Per hour
	Dollars			
Yarder[1]:				
Fuel and lubrication	7.67	0.96	5.97	0.75
Labor:				
7-man crew	144.08	18.01		
5-man crew			104.20	13.03
Payroll overhead	31.70	3.96	22.92	2.86
Subtotal	175.78	21.97	127.12	15.89
Total	183.45	22.93	133.09	16.64

[1] Same equipment as in table 20.

Table 23.—Direct loading costs for fuel and labor in high-lead operations near Cosmopolis, Wash., 1961

Item	Regular yarding (1-yard model)		Relog yarding (3/4-yard model)	
	Per day	Per hour	Per day	Per hour
	Dollars			
Loader[1]:				
Fuel and lubrication	8.00	1.00	6.80	0.85
Labor:				
Two men	47.24	5.90	47.24	5.90
Payroll overhead	10.39	1.30	10.39	1.30
Subtotal	57.63	7.20	57.63	7.20
Total	65.63	8.20	64.43	8.05

[1] Same equipment as in table 21.

Table 24.—Hauling cost per trip, excluding depreciation and related items, in high-lead operations near Cosmopolis, Wash., 1961, by average log volume and hauling distance[1]

Average log volume (cubic feet)	Hauling distance (miles)						
	10	20	30	40	50	60	70
	Dollars						
2.5-5	13.04	21.51	29.36	36.93	44.48	52.05	59.60
10	12.48	20.95	28.80	36.37	43.92	51.49	59.04
25	10.78	19.25	27.10	34.67	42.22	49.79	57.34
50	10.22	18.69	26.54	34.11	41.66	49.23	56.78
100	9.93	18.40	26.25	33.82	41.37	48.94	56.49
150	9.88	18.35	26.20	33.77	41.32	48.89	56.44

[1] Developed from data of tables 9 and 10.

GPO 988-325

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ECONOMIC COMPARISON OF
RELOGGING and
CLEAN LOGGING
in mature hemlock

by Thomas C. Adams

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Assistance and cooperation by Kenneth N. Wiley and James E. King of the Weyerhaeuser Co., Forestry Research Center, and by William R. Johnson and Amual C. Knutz, Clemons Branch Managers, Weyerhaeuser Co., is acknowledged.

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Introduction

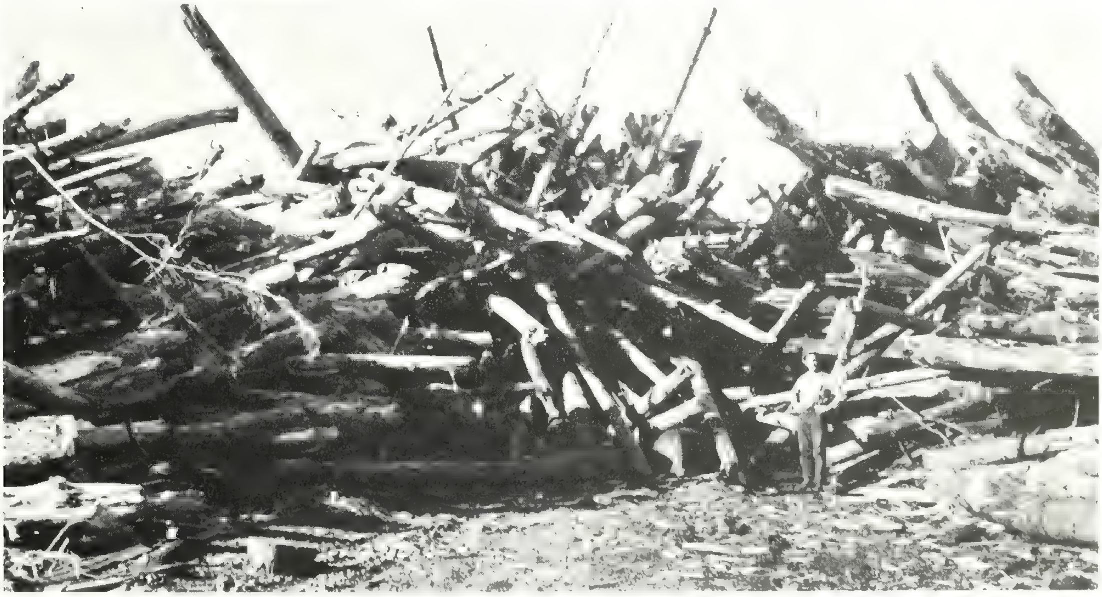
Clearcutting mature timber by conventional high-lead methods often leaves considerable volumes of logging residue in the form of tops and small trees. Forest managers in the Douglas-fir subregion of Oregon and Washington are seeking ways to increase forest utilization by developing more economic methods for harvesting this small material (fig. 1). Two such methods being tried are relogging and clean logging. In both methods, an entire setting is clearcut in the usual way. The **relogging** method of this study accomplishes high-lead yarding in two stages, in which the second or relog yarding operation uses the same spar tree but smaller equipment and a smaller crew to achieve lower direct logging costs. The first stage, or main yarding operation, can then concentrate on the large pieces. The **clean-logging** method yards and loads all material, including the small pieces, in a single stage. Both methods employed an extra pulpwood trailer and a loading crib or "sled" at the landing for bundling of small pulp material under 20 feet in length to reduce loading time.

Two methods of relogging were studied. One involved cold decking at the landing; the other "hot" loaded logs as they were yarded into the landing.

Objectives of the study were to determine the most profitable logging procedure and combination of equipment among those tested and to suggest ways for improving efficiency by increasing or decreasing the volumes left for relogging.

Operations were conducted on seven clearcut settings in the Bishop Road area of Weyerhaeuser Co.'s Clemons Tree Farm, near Cosmopolis, Wash., where the company operates a sulfite pulpmill supplied by raw material from the tree farm.

Figure 1.—The Cosmopolis pulpmill provides a market for small pieces and broken chunks. Should they be yarded in the main operation or left for relogging, as shown? (Photo courtesy of Weyerhaeuser Co.)



Procedure

The study was conducted in the spring of 1961 in a 110-year-old mature stand of western hemlock, which included associated species of true firs, Sitka spruce, western redcedar, and Douglas-fir (figs. 2 and 3). Stand conditions were generally uniform among the several settings. Average net volume per acre was 54,000 board feet, including board-foot equivalent of pulpwood. Average area of the settings was 10.4 acres, with a range of 5.7 to 14.0 acres. Elevation was approximately 850 feet above sea level.

The following logging plans outline the three methods of yarding and loading that were tested. Felling and bucking were the same under each plan.

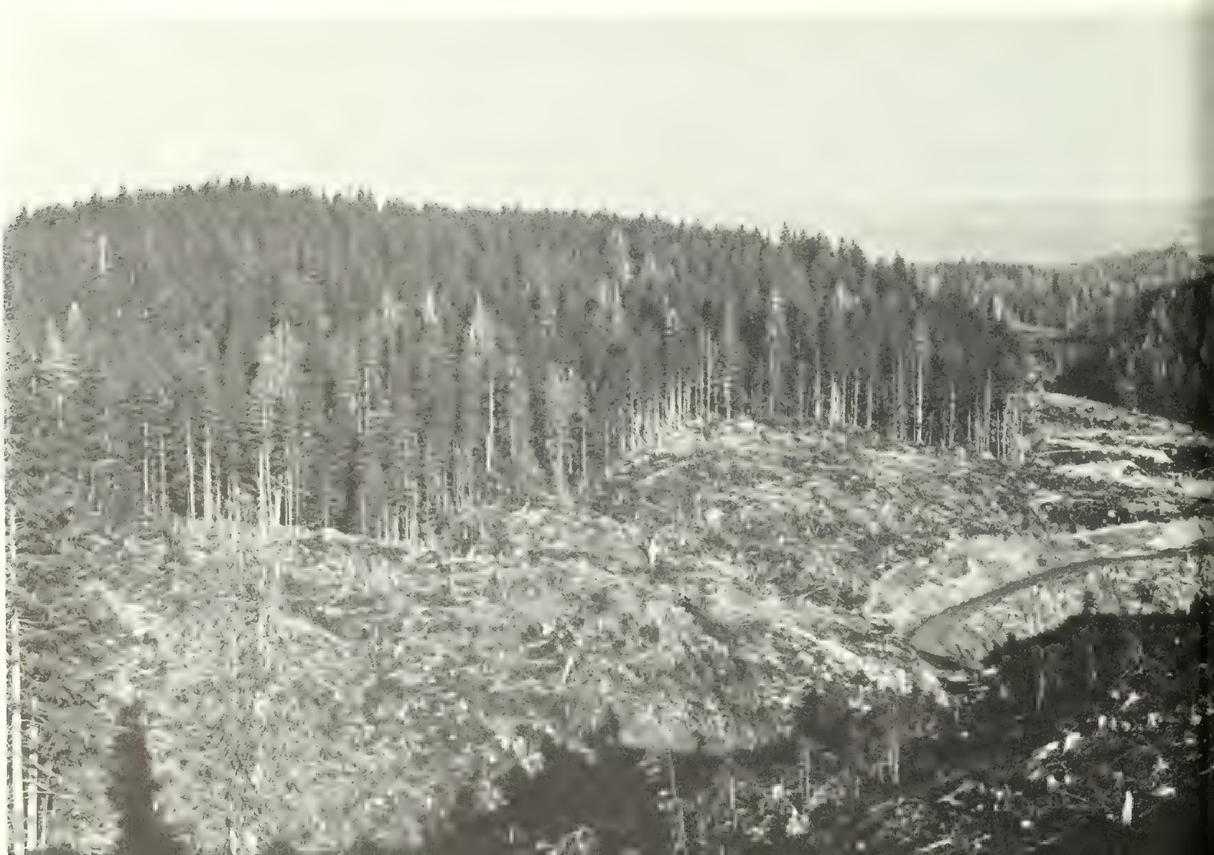
Plan I. Clean Logging (Three Settings)

1. Yarded all material with a 4-inch or larger top diameter, 8 feet or more in length, with regular high-lead equipment and a seven-man crew and two or three chokers. Used standard triple-drum yarding unit mounted on the rear of a crawler tractor (235 horsepower). Yarding labor and equipment cost was calculated as $28.56 per hour.

2. Loaded out all logs over 26 feet in length, plus shorter saw logs, with standard semitrailer log trucks. Used 1-yard loader equipped with tong line.

3. Loaded as many as possible of the pulp pieces into standby sled or separate short trailer when loader was not loading out the larger logs.

Figure 2.—Studies were conducted in 110-year-old stand of mature western hemlock near Cosmopolis, Wash.



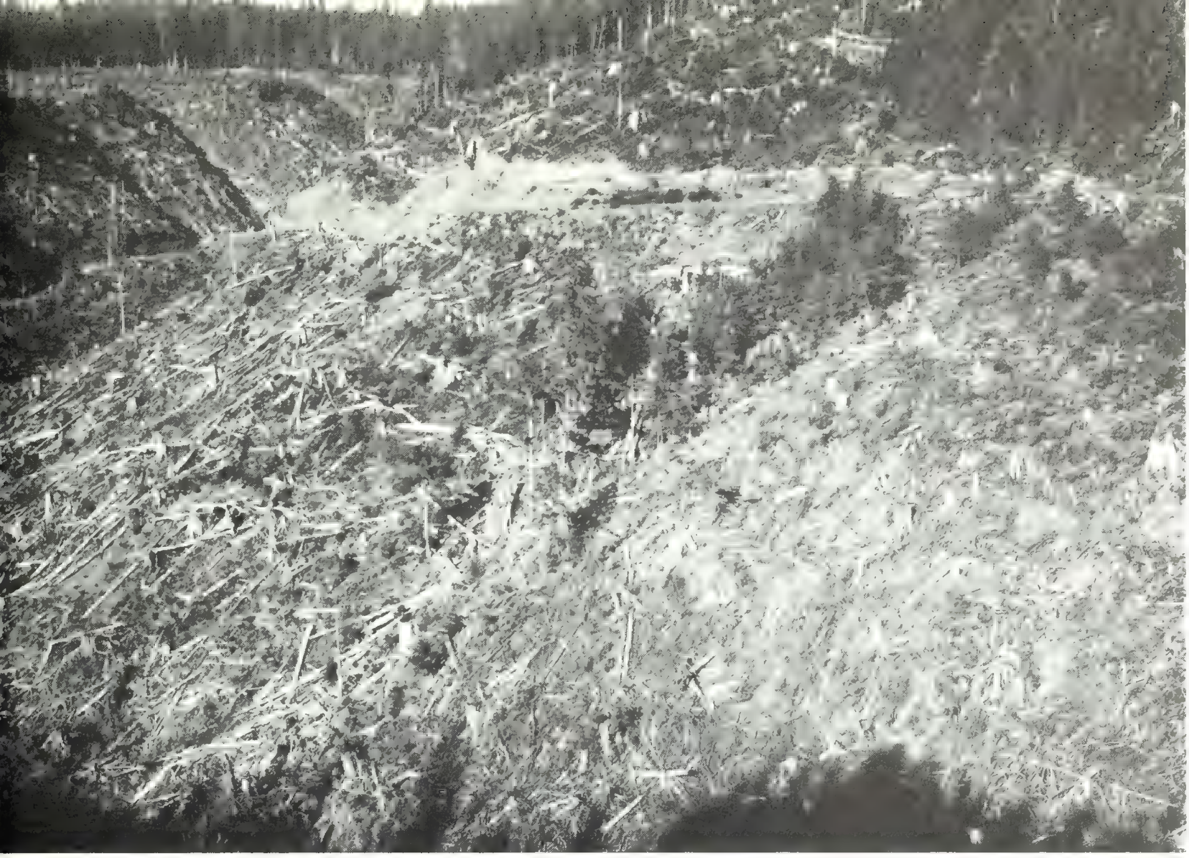


Figure 3.—Area on right was relogged soon after main harvest. The older cutting area on the left, not relogged, is in another ownership and was cut about 10 years previously, before development of a pulpwood market.

Plan II. Relogging Direct to Trucks (One Setting)[1]

1. Yarded, loaded, and hauled out all material down to 10-inch diameter by 26 feet in length, plus any shorter pieces too large for relogging, using a seven-man crew and the same type of heavy equipment as in plan I. Left spar tree rigged for relogging. Yarding labor and equipment cost with this method was $20.67 per hour.

2. Relogged the remaining pieces 4 inches by 8 feet to 10 inches by 26 feet, using light lines, three chokers, a five-man crew, and small triple-drum tractor yarder (125 horsepower).

3. In both stages, loaded concurrently with yarding. Loaded first stage with 1-yard loader. Loaded second stage to sled or short truck and trailer with 3/4-yard loader equipped with tong line or hydraulic tongs. So far as possible, loaded the sled and separate trailer while short truck and trailer combination was making trip to mill yard (fig. 4).

Plan III. Relogging to Cold Deck (Three Settings)

1. Same as plan II, except that relogging was to cold deck. Loaded out after relogging to cold deck was completed (fig. 5).[2]

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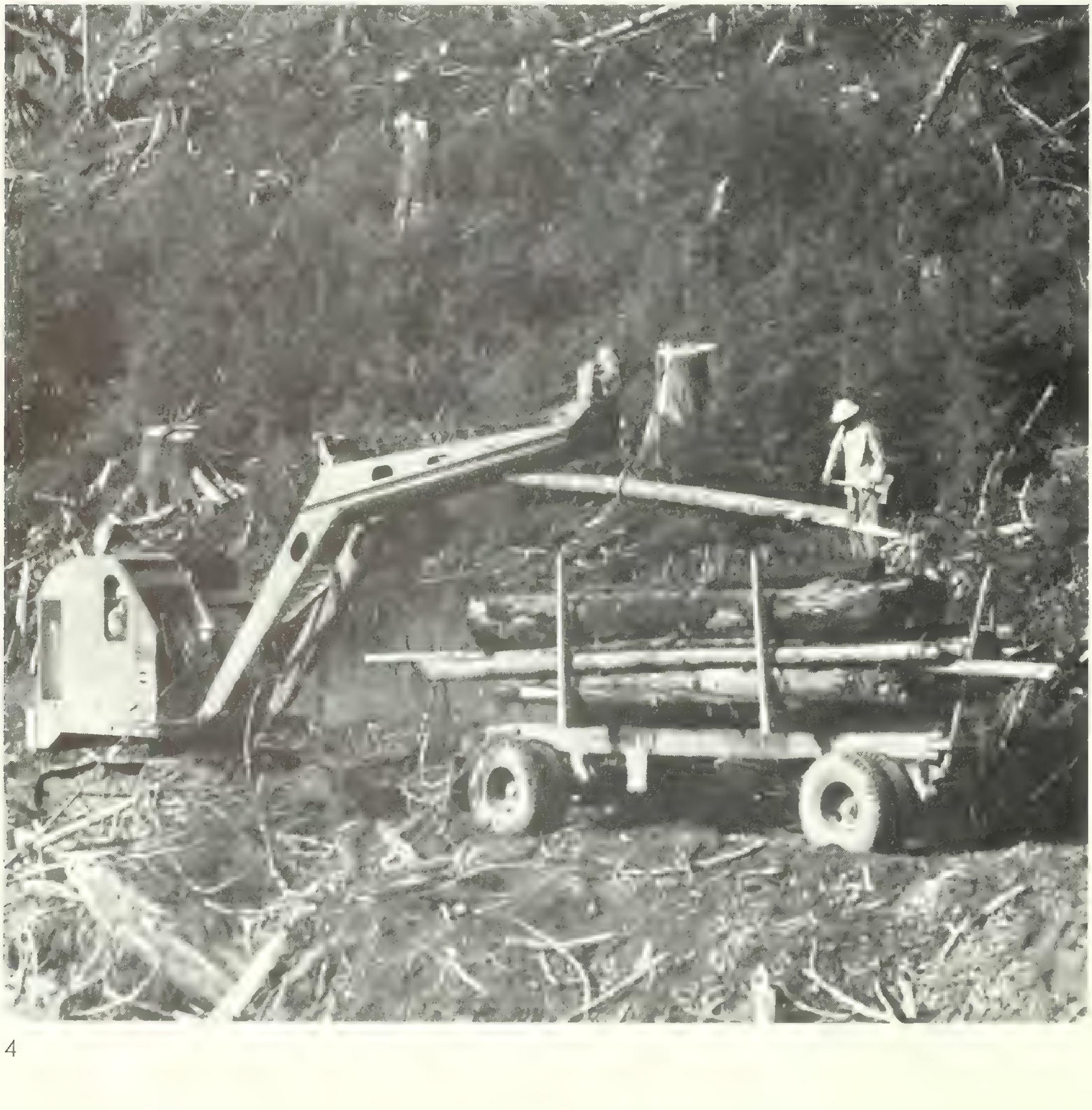
[1] Originally, the study called for two settings each under plans II and III; this was later modified to accommodate the work schedule of the company.

[2] One of the three settings in plan III provided relogging data only. The first-stage logging had been completed prior to start of the study.

Figure 4.—An extra 4-wheel trailer cuts loading time in relogging operations.



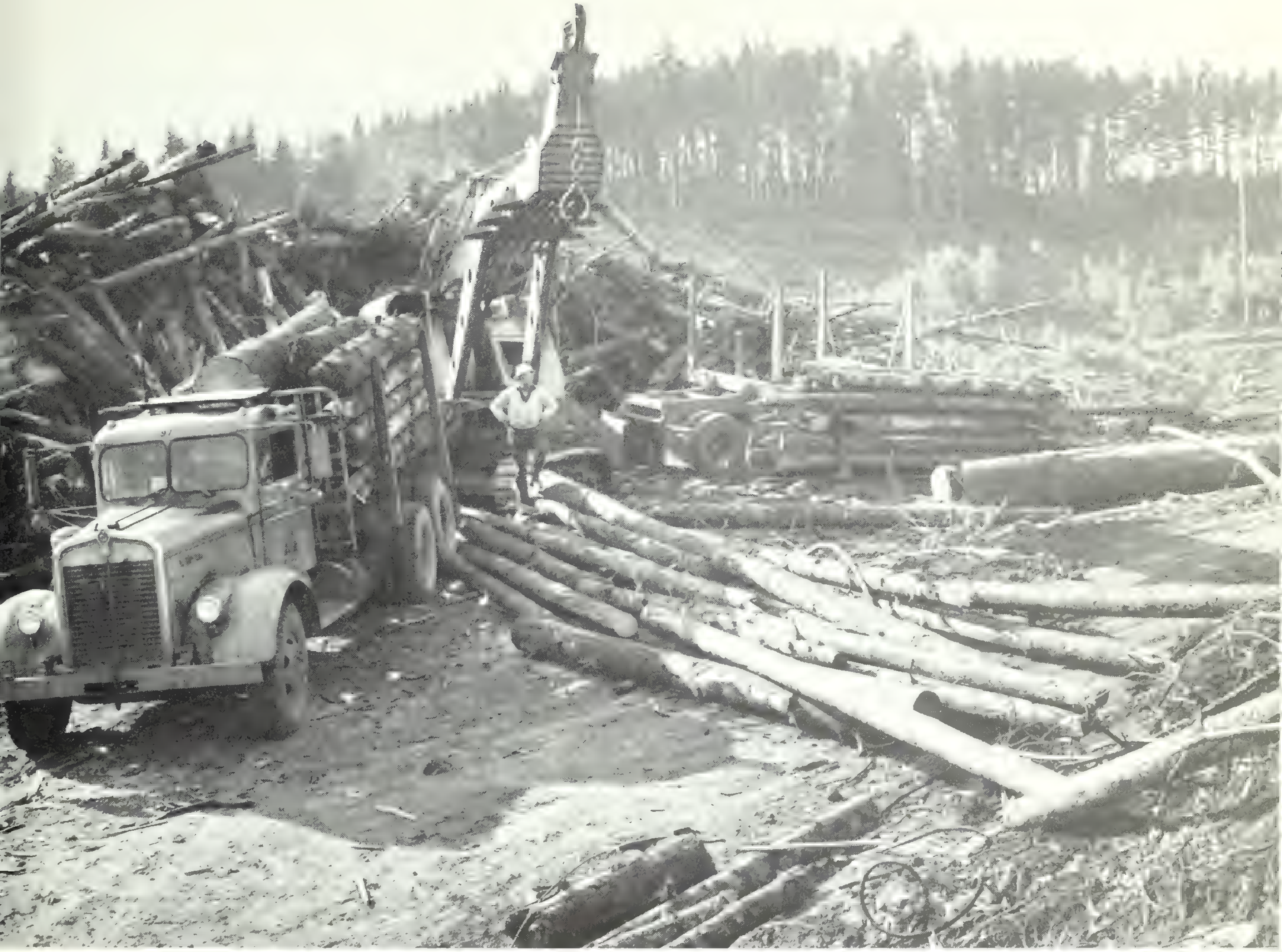


Figure 5—Relogging employed a 3/4-yard loader and short truck and trailer combination. A loading crib or sled permitted making up partial loads in slack time and further reduced loading time for trucks. (Photo courtesy of Weyerhaeuser Co.)

Measurement of Volume and Area

The volumes removed from each setting were determined from scaling records at unloading points. Separate log brands were used to identify truck loads with their setting. All saw logs were scaled by Scribner log rule. All pulp loads were weighed, with 37 percent of the loads also scaled directly to give weight conversion factors for each setting. Pulp material below saw log size was scaled in cubic feet and converted to cords on the basis of 90 cubic feet per cord, then to board feet at 2 cords per thousand board feet. This corresponds to measurement and accounting practices of the company. The few Douglas-fir and western redcedar logs of less than saw log size were excluded from the study.

The available volume on any setting was considered as consisting of two parts: first, the main volume which would be removed under either method, and second, the extra volume recovered in small pieces by the relogging operation which would not have been recovered by the one-stage clean logging.

A 100-percent inventory was made of logging residue, which included all material down to 4 inches by 8 feet. Standing live and dead trees were tallied if they included material meeting relogging standards.

Area of each setting was determined by photogrammetric methods from large-scale aerial photos taken immediately after logging.

Production Rates

The Weyerhaeuser Co. cooperated in developing daily production rates. In addition to making special arrangements for scaling and recording the output from each setting, the logging superintendent provided a running record of operating times for each crew and for each piece of yarding and loading equipment. Short working delays of less than one-half hour were included in total times used in calculation of daily production rates. Longer delays, such as those for repairs, shutdowns due to dangerous winter weather conditions, or other causes, were excluded.

Development of Cost Data

Unit costs were developed separately for clean logging and for each stage of the relogging method. These costs excluded items that were the same for both methods, such as felling and bucking, road construction and maintenance, fire protection, initial rigging of spar tree, and initial moving in of logging equipment. Hauling costs for the equivalent clean-logging volume were also excluded because they, too, were assumed to be the same under both methods. Hauling cost for the extra volume from relogging, however, was included.

Items of logging burden and administrative overhead were excluded on the assumption that there was no extra expense to the company as a result of relogging. It was considered that the extra work of logging foreman and high climber could be absorbed without employing more men or restricting operations elsewhere.

Hourly costs were developed for yarding and loading operations. These consisted of direct costs for wages, fuel, lubrication, and materials, plus a proportionate share of annual fixed equipment charges for depreciation, interest, taxes, and insurance, prorated on an hourly basis. These fixed costs were included because they are different for the different methods and, in this sense, variable according to choice of method.

Hauling costs for the extra volume from relogging were calculated according to the Washington Utilities and Transportation Commission rates[3], adjusted for defect and profit and risk.

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[3] Washington Utilities and Transportation Commission, Tariff No. 4-A. Pp. 34-34A. Olympia, Wash. 1963.

Economic Analysis

Detailed results of this study, in terms of time and production data, are shown in tables 4 through 12 in the appendix. In order to compare the two logging methods on an equal basis, the time and production data were related to a hypothetical 10-acre setting and removal of 50,000 board feet per acre (including pulpwood equivalent). Based on actual production data, clean yarding of all material down to pieces 4 inches by 8 feet (500,000 board feet) would take 12.5 days, exclusive of rigging and unrigging time. Alternatively, under the relogging method, first-stage yarding of material down to 10 inches by 26 feet (434,500 board feet) would take 8.2 days, followed by 6.6 days of relog yarding to a 4-inch by 8-foot minimum size piece (68,600 board feet) plus 0.6 day extra rig-up time. Production rates used in the model exclude data from setting number 7, which had been clean logged prior to decision to relog it for this study. Physical data from this setting, however, are included in some of the appendix tables and are useful to illustrate the sharp drop in production associated with low relog volumes per acre.

Although both the relogging and clean-logging methods were designed to remove material down to a 4-inch by 8-foot minimum, the two-stage or relogging method yielded 0.63 percent more volume, or the equivalent of 3,145 board feet additional for a 500,000-board-foot setting.

Analysis Under Observed Conditions

An economic analysis was made to determine which logging method gave the greatest addition to net revenue after taxes or net extra cost. This amount is composed of two elements: the value of any extra yield produced and any cost saving of one method compared with the other. This net revenue figure takes into account the effect of the 52-percent corporate income tax and a 27-percent capital gains tax saving on the extra volume of wood produced. This capital gains tax saving is the difference between the 25-percent capital gains tax rate and the ordinary 52-percent rate, applied to fair market value minus depletion.[4]

Under average operating conditions of the study and an assumed depletion rate of $1 per thousand board feet and fair market value of $16 per thousand board feet of private stumpage, the relogging method was found to be $130.19 more costly for a hypothetical 10-acre setting than clean logging (table 1).[5]

Unit costs of table 1 are from labor and machine rates and other data, developed in appendix tables 13 through 15. Loading machine rates used in the basic calculations were for crawler-type loaders equipped with tong lines (table 14).

The extra yield from relogging is valued at $18.50 per cord, or $37 per thousand board feet. This represents the approximate cost of purchased pulpwood delivered to the mill. This procedure recognizes that any additional company-produced wood can substitute for purchased wood, which would normally be the most expensive outside wood.

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[4] The corporate income tax rate was 52 percent prior to January 1, 1964. This rate was changed to 50 percent from January 1, 1964, and to 48 percent after January 1, 1965. Calculations are shown at the 52-percent rate.

[5] This difference represents the best estimate of the difference between methods. However, due to the small number of replications and the variation in results among the three settings of each method, it is not possible to establish this as a statistically significant difference by the usual standards.

Table 1.—Comparison of costs of relogging versus clean logging, in 110-year-old western hemlock near Cosmopolis, Wash., 1961[1]

Item	Unit cost		Total pertinent cost
	Per hour[2]	Per M bd. ft.[3]	
	Dollars		
TWO-STAGE LOGGING			
Main logging, 434,500 board feet:			
Yarding, 8.2 days x 8 hours = 65.6 hours	28.56	4.31	1,873.54
Loading, 8.2 days x 8 hours = 65.6 hours	15.97	2.41	1,047.63
Relogging, 68,600 board feet:			
Moving in, 0.6 day x 8 hours = 4.8 hours	20.67	1.45	99.22
Yarding, 6.6 days x 8 hours = 52.8 hours	20.67	15.91	1,091.38
Loading, 6.5 days x 8 hours = 52.0 hours	14.11	10.70	733.72
Total pertinent cost		9.63	4,845.49
Additional hauling, 3,145 board feet at $6.88 per thousand		6.88	21.64
Total costs			4,867.13
ONE-STAGE LOGGING			
Clean logging, 500,000 board feet:			
Yarding, 12.5 days x 8 hours = 100 hours	28.56	5.71	2,856.00
Loading, 12.5 days x 8 hours = 100 hours	15.97	3.19	1,597.00
Total pertinent cost		8.90	4,453.00
ANALYSIS			
Obtaining extra wood by relogging (two-stage logging):			
Extra cost ($4,867.13 - $4,453.00)			414.13
Income tax reduction (0.52 x $414.13)			215.35
Net extra cost after 52-percent reduction			198.78
Capital gain (3,145 board feet x ($16-$1) = $47.175)			
Saving from capital gains tax, 0.52 x $47.175 = $24.53			
Capital gains tax, 0.25 x $47.175 = 11.79			
Net capital gains tax saving 12.74			12.74
Net extra cost after income tax and capital gains tax			186.04
Obtaining extra wood by purchase (one-stage logging):			
Extra cost of purchased pulpwood ($37 x 3,145 board feet)			116.36
Income tax reduction (0.52 x $116.36)			60.51
Net extra cost of purchasing extra pulpwood			55.85
Comparison of alternatives:			
Net extra cost of relogging			186.04
Net extra cost of purchasing extra pulpwood			55.85
Net extra cost of two-stage logging, instead of one-stage logging and purchase of 3,145 board feet of extra wood			130.19

[1] Includes board-foot equivalent of pulpwood.
[2] Developed from appendix tables 13 through 15.
[3] Derived from total pertinent costs.

More Favorable Alternatives Suggested

Even though daily production in yarding averaged 52,800 board feet in the first stage of the relogging method, it averaged only 10,400 board feet in the second-stage operation as compared with 40,000 board feet for clean logging (table 6). This low production in the second stage was due chiefly to the time lost in road changing (changing of tail blocks and corner blocks for haulback line). It was also due partly to the low relog volume, 6,860 board feet per acre. An additional analysis was made to show the calculated effect of an increase in volume per acre left for relogging (table 2). If twice the volume were left, then the daily production in relog yarding would be increased to 15,800 board feet, and there would be a gain in net revenue of $54.60 per setting over clean logging (table 3, method C).

Table 2.—Comparison of clean logging and relogging under different utilization standards and relogging volumes per acre, in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Method	Minimum utilization standard	Relogging volume per acre[1]	Yield per 500,000-board-foot setting	Number of days per setting[2]		Number of settings per year	
				At average rate	At rate of setting number 3[3]	At average rate	At rate of setting number 3[3]
		M bd. ft.	M bd. ft.				
A (clean logging)	4 inches by 8 feet	—	500	14.0	—	17.1	—
B (relogging)	4 inches by 8 feet	6.86	503.1	7.2	5.6	33.3	42.9
C (relogging)	4 inches by 8 feet	13.7	503.1	9.3	7.7	25.8	31.2
D (clean logging)	7 cubic feet	—	496.6	13.4	—	17.9	—
E (relogging)	5 cubic feet	6.53	499.3	6.2	4.6	38.7	52.2
F (relogging)	5 cubic feet	13.1	499.3	8.8	7.2	27.3	33.3

[1] Includes board-foot equivalent of pulpwood measured in cubic feet.

[2] Includes 1.5 days to move in and rig up for clean logging; 0.6 day for relogging.

[3] Setting number 3 had the most favorable relogging production rate.

Table 3.—Estimated gain or loss in net revenue of other methods over method A, in logging 110-year-old western hemlock near Cosmopolis, Wash., 1961

Method	Gain or loss at average rate				Gain or loss at rate of setting number 3			
	Per thousand board feet	Per setting	Per year	Rate of return[1]	Per thousand board feet	Per setting	Per year	Rate of return[1]
	Dollars	Dollars	Dollars	Percent	Dollars	Dollars	Dollars	Percent
A (clean logging)	—	—	—		—	—	—	—
B (relogging)	-0.259	-130.19	-4,335	([2])	0.155	78.08	3,350	5.5
C (relogging)	.109	54.60	1,409	2.3	.441	222.00	6,926	11.4
D (clean logging)	.093	46 27	828	—	—	—	—	—
E (relogging)	-.107	-53.30	-2,063	([2])	.310	154.98	8,090	13.3
F (relogging)	.126	62.90	1,717	2.8	.501	250.17	8,331	13.7

[1] Rate of return on initial investment of $60,930 including relog yarder, loader, landing equipment, rigging, and 24 chokers.

[2] Negative.

Setting number 3 was more favorable for relogging than the average, due chiefly to stand conditions and topography. Production rates of setting number 3 showed a potential gain of $78.08 per 10-acre setting at observed relog volume, or $222 per setting if twice the observed material were left for relogging.

A marginal log study of direct costs and values, conducted concurrently with this study, indicated that material as small as 4 inches by 8 feet would generally be uneconomic by either method.[6] This study did not take into account other reasons that could be advanced for the 4-inch by 8-foot utilization standard, such as reduction of slash hazard, more favorable site preparation for regeneration, a more esthetic appearance of the land after logging, or a condition where raw material supply might be a limiting factor to the company's manufacturing production.

From the data on size distribution of individual logs, a cost comparison was made under the assumption of clean logging to a 7-cubic-foot minimum. This showed a gain in net revenue of $46.27 per 10-acre setting over clean logging to 4 inches by 8 feet (table 3, method D). The two-stage relogging method to a 5-cubic-foot minimum showed even greater potential gains.

The limits of 7 cubic feet under clean logging and 5 cubic feet under relogging represent break-even log volumes, under the conditions of this study, for a yarding distance of 300 feet. Actual break-even log volumes for clean logging and relogging were calculated as 5 and 4 cubic feet, respectively, at 100-foot yarding distance and 10 and 6 cubic feet at 600-foot yarding distance.

Gains of methods D, E, and F of table 3 are not simply due to increased productivity from handling larger material; they are from avoidance of actual net losses in handling uneconomic material.

RATES OF RETURN FROM RELOGGING.—Table 3 also shows calculated rates of return potentially available from an initial investment of $60,930 in relogging equipment. These range from 2.3 percent for method C to 13.7 percent for method F.

COLD VERSUS HOT LOADING.—A comparison was made of yarding and loading production rates with relogging and loading direct to trucks (hot loading), and relogging to a cold deck (table 12). Hourly production in both yarding and loading was greater with hot loading than with cold decking. Some of this difference, however, can be attributed to more volume per piece, more volume per acre, and slightly better ground on the hot-loaded setting.

Average unhooking and loading times for the two methods were:

	Hot loading	Cold decking
	(minutes)	
Unhooking time (per turn)	0.83	1.18
Loading time (per piece)	.85	1.02

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[6] Adams, Thomas C. High-lead logging costs as related to log size and other variables. Pacific NW. Forest & Range Expt. Sta., U. S. Forest Serv., Res. Paper PNW-23, 38 pp., illus. 1965.

Conclusions

Forest managers are interested in potential opportunities for increased timber utilization. Economic analysis can provide guidelines to alternative logging methods that promise lower unit costs by employing relatively small equipment and small crews for the smaller logs.

Even though the trial two-stage relogging operations studied were a little more costly than single-stage or clean logging, they provided the data for discovering critical cost factors and for suggesting modified procedures that could be even more profitable. They demonstrate the value of economic analysis that can be tailored to fit the conditions existing on a particular area.

There will be an increasing need for economical logging methods and equipment for handling the increasing volume of small material that will be encountered in western logging operations. The two-stage relogging method is only one alternative. Contract relogging, either by high lead, small tower, jammer, or crawler tractor are other possibilities. Another alternative to be explored is that prelogging of the smaller trees might have resulted in even greater volume recovery, through less breakage, and in lower unit costs.

Where raw material supply is not a limiting factor, some cost savings are possible with even single-stage logging if the minimum utilization standard can be defined more closely and be made more flexible in relation to market requirements.

Appendix

Table 4.—Area, external yarding distance, and volume yarded on study settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Setting number	Area	External yarding distance[1]		Volume yarded per acre[2]		
		Maximum	Average	Main logging	Re-logging	Total
	Acres	Feet	Feet	— —	M bd. ft.	— —
Clean-logged settings:						
2	11.4	640	390	--	--	56.4
4	10.7	720	400	--	--	55.7
6	14.0	610	440	--		44.2
Subtotal or average	36.1	657	410	--	--	51.4
Relogged settings:						
1	7.6	480	400	44.3	6.4	50.7
3	11.4	550	420	53.4	8.6	61.9
5	5.7	610	410	35.8	6.1	42.1
7	[3](12.3)	[3](740)	[3](540)	--	[3](3.1)	--
Subtotal or average	24.7	527	410	46.5	7.3	53.9
Average	[4]10.1	592	410	46.5	7.3	52.4

[1] Horizontal distance to edge of setting.

[2] Includes board-foot equivalent of pulpwood calculated at 1 cubic foot = 5.556 board feet, from formula: board feet = $\frac{\text{cubic feet}}{90} \times 500$.

[3] Data in parentheses not included in subtotal or averages.

[4] 10.4 including setting number 7.

Table 5.—Machine time and production in yarding on study settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Setting number	Machine time[1]			Volume yarded[2]		
	Main logging	Re-logging	Total	Main logging	Re-logging	Total
	— — —	Hours	— — —	—	M bd. ft.	— —
Clean-logged settings:						
2	--	--	126.5	--	--	642.4
4	--	--	115.5	--	--	595.9
6	--	--	129.5	--	--	618.8
Total	--	--	371.5	--	--	1,857.1
Relogged settings:						
1	59	45	104	336.8	48.8	385.6
3	78	59	137	608.3	97.6	705.9
5	37	33.5	70.5	204.2	34.9	239.1
7	--	[3](61.5)	--	--	[3](38.3)	--
Total	174	137.5	311.5	1,149.3	181.3	1,330.6

[1] Machine time includes operating delays (e.g., hangups, changing guy lines, swinging blocks, moving yarders, and minor delays at the landing). It excludes breakdown time, which in this study averaged 0.0168 hour per hour of machine time. Machine time also excludes time for moving in equipment and rig-up (1.5 days per setting for clean logging and main logging, 0.6 day per setting for relogging).

[2] Includes board-foot equivalent of pulpwood calculated at 1 cubic foot = 5.556 board feet, from formula: board feet = $\frac{\text{cubic feet}}{90} \times 500$.

[3] Data in parentheses not included in subtotals or averages.

Table 6.—Machine production rates in yarding on study settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Setting number	Volume yarded[1] per hour			Volume yarded[1] per 8-hour day			Days to yard 500,000 board feet		
	Main logging	Re-logging	Average	Main logging	Re-logging	Average	Main logging	Re-logging	Average
	M bd. ft.								
Clean-logged settings:									
2	--	--	5.1	--	--	40.8	--	--	12.3
4	--	--	5.1	--	--	40.8	--	--	12.3
6	--	--	4.8	--	--	38.4	--	--	13.0
Average	--	--	5.0	--	--	40.0	--	--	12.5
Relogged settings:									
1	5.7	1.1	3.7	45.6	8.8	29.6	11.0	56.8	16.9
3	7.8	1.7	5.2	62.4	13.6	41.6	8.0	36.8	12.0
5	5.5	1.0	3.4	44.0	8.0	27.2	11.4	62.5	18.4
7	--	[2] (0.6)	--	--	[2] (4.8)	--	--	[2] (104.2)	--
Average	6.6	1.3	4.3	52.8	10.4	34.4	9.5	48.1	14.5

[1] Includes board-foot equivalent of pulpwood calculated at 1 cubic foot = 5.556 board feet, from formula: board feet $= \frac{\text{cubic feet}}{90} \times 500$.

[2] Data in parentheses not included in subtotals or averages.

Table 7.—Machine time and production in loading on study settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Setting number	Machine time[1]			Volume removed[2]			Volume removed[2] per hour			Volume removed[2] per 8-hour day		
	Main logging	Re-logging	Total	Main logging	Re-logging	Total	Main logging	Re-logging	Average	Main logging	Re-logging	Average
	Hours			M bd. ft.								
Clean-logged settings:												
2	--		124	-		641.4	--		5.2			41.6
4	--	--	118.5	--	--	592.7	--	--	5.0	--	--	40.0
6	-	--	120.5	.	--	618.0	--	--	5.1	--	--	40.8
Total or average	--	--	363	--	-	1,852.1	--		5.1	--	--	40.8
Relogged settings:[3]												
1	60	37	97	336.8	47.7	384.5	5.6	1.3	4.0	44.8	10.4	32.0
3	84	69	153	608.3	97.0	705.3	7.2	1.4	4.6	57.6	11.2	36.8
5	38	28	66	204.2	31.0	235.2	5.4	1.1	3.6	43.2	8.8	28.8
7	--	[4](35)	--	--	[4](36.9)	--	-	[4](1.1)			[4](8.8)	--
Total or average	182	134	316	1,149.3	175.7	1,325.0	6.3	1.31	4.2	50.4	10.5	33.6

[1] Machine time includes operating delays (e.g., waiting for yarder, logs, or trucks). It excludes breakdown time, which in this study averaged 0.00910 hour per hour of machine time.

[2] Includes board-foot equivalent of pulpwood calculated at 1 cubic foot = 5.556 board feet, from formula: board feet = $\frac{\text{cubic feet}}{90} \times 500$.

[3] Settings 1, 5, and 7 were cold-decked settings; setting 3 was hot loaded.

[4] Data in parentheses not included in subtotals or averages.

Table 8.—Pulpwood logging residue, by size class and location, on clean-logged settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Location	Setting number	Area, in acres	Diameter, 6 inches and larger				Diameter, 4 - 5.9 inches only				Diameter, 4 inches and larger				
			Number of logs	Cubic feet	Average cubic feet per log	Cubic feet per acre	Number of logs	Cubic feet	Average cubic feet per log	Cubic feet per acre	Number of logs	Cubic feet	Board-foot equivalent per log	Average cubic feet per log	Cubic feet per acre
Off landing	2	11.4	87	420	4.8	36.8	211	359	1.7	31.5	298	779	4,328	2.6	68.3
At landing			26	164	6.3	14.4	9	15	1.7	1.3	35	179	995	5.1	15.7
Total		11.4	113	584	5.2	51.2	220	374	1.7	32.8	333	958	5,323	2.9	84.0
Off landing	4	10.7	61	296	4.8	27.7	159	322	2.0	30.1	220	618	3,434	2.8	57.8
At landing			66	488	7.4	45.6	48	90	1.9	8.4	114	578	3,211	5.1	54.0
Total		10.7	127	784	6.2	73.3	207	412	2.0	38.5	334	1,196	6,645	3.6	111.8
Off landing	6	14.0	206	1,434	7.0	102.4	206	324	1.6	23.2	412	1,758	9,767	4.3	125.6
At landing			23	94	4.1	6.7	37	48	1.3	3.4	60	142	789	2.4	10.1
Total		14.0	229	1,528	6.7	109.1	243	372	1.5	26.6	472	1,900	10,556	4.0	135.7
Total off landing		36.1	354	2,150	6.1	59.6	576	1,005	1.7	27.8	930	3,155	17,529	3.4	87.4
Total at landing			115	746	6.5	20.7	94	153	1.6	4.2	209	899	4,995	4.3	24.9
Total		36.1	469	2,896	6.2	80.2	670	1,158	1.7	32.1	1,139	4,054	22,524	3.6	112.3

Table 9.—Pulpwood logging residue, by size class and location, on relogged settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Location	Setting number	Area, in acres	Diameter, 6 inches and larger				Diameter, 4 - 5.9 inches only				Diameter, 4 inches and larger				
			Number of logs	Cubic feet	Average cubic feet per log	Cubic feet per acre	Number of logs	Cubic feet	Average cubic feet per log	Cubic feet per acre	Number of logs	Cubic feet	Board-foot equiv-alent per log	Average cubic feet per log	Cubic feet per acre
Off landing	1	7.6	49	212	4.3	27.9	111	130	1.2	17.1	160	342	1,900	2.1	45.0
At landing			28	115	4.1	15.1	57	88	1.5	11.6	85	203	1,128	2.4	26.7
Total		7.6	77	327	4.2	43.0	168	218	1.3	28.7	245	545	3,028	2.2	71.7
Off landing	3	11.4	26	96	3.7	8.4	63	83	1.3	7.3	89	179	995	2.0	15.7
At landing			8	57	7.1	5.0	35	54	1.5	4.7	43	111	617	2.6	9.7
Total		11.4	34	153	4.5	13.4	98	137	1.4	12.0	132	290	1,612	2.2	25.4
Off landing	5	5.7	17	53	3.1	9.3	113	160	1.4	28.1	130	213	1,183	1.6	37.4
At landing			99	495	5.0	86.8	127	204	1.6	35.8	226	699	3,884	3.1	122.6
Total		5.7	116	548	4.7	96.1	240	364	1.5	63.9	356	912	5,067	2.6	160.0
Off landing	7	12.3	27	112	4.2	9.1	40	58	1.4	4.7	67	170	945	2.5	13.8
At landing			21	141	6.7	11.5	78	106	1.4	8.6	99	247	1,372	2.5	20.1
Total		12.3	48	253	5.3	20.6	118	164	1.4	13.3	166	417	2,317	2.5	33.9
Total off landing		24.7	92	361	3.9	14.6	287	373	1.3	15.1	379	734	4,078	1.9	29.7
Total at landing			135	667	4.9	27.0	219	346	1.6	14.0	354	1,013	5,629	2.9	41.0
Total[1]		24.7	227	1,028	4.5	41.6	506	719	1.4	29.1	733	1,747	9,707	2.4	70.7

[1] Totals exclude data for setting number 7.

Table 10.—Analysis of logging residue on study settings in 110-year-old western hemlock near Cosmopolis, Wash., 1961[1]

Type of logging and setting number	Area	Volume removed	Original volume[2]		Residue off landing		
			Total	Per acre	Total	Per acre	Per million board feet original volume
	Acres	M bd. ft.	— — — M bd. ft.	— — —	Bd. ft.	Bd. ft.	M bd. ft.
Clean-logged settings:							
2	11.4	641.4	646.7	56.7	4,328	380	6.69
4	10.7	592.7	599.3	56.0	3,434	321	5.73
6	14.0	618.0	628.6	44.9	9,767	698	15.54
Total or average	36.1	1,852.1	1,874.6	51.9	17,529	486	9.35
Relogged settings:							
1	7.6	384.5	387.5	51.0	1,900	250	4.90
3	11.4	705.3	706.9	62.0	995	87	1.41
5	5.7	235.2	240.3	42.2	1,183	208	4.92
7	[3](12.3)	--	--	--	[3](945)	[3](77)	--
Total or average	24.7	1,325.0	1,334.7	54.0	4,078	165	3.06
Extra volume from relogging	--	--	--	--	--	--	6.29

[1] In pieces 4 inches by 8 feet and larger, off landing, converted to board feet by formula: board feet $= \frac{\text{cubic feet}}{90} \times 500.$

[2] Calculated as sum of volume removed plus total residue on and off landing.

[3] Data in parentheses not included in subtotals or averages.

Table 11.—Production rates in relog yarding and loading, by type of setting, in 110-year-old western hemlock near Cosmopolis, Wash., 1961[1]

Type and setting number	Yarding				Loading	
	Machine time	Production	Production per hour	Machine time	Production	Production per hour
	Hours	— — M bd. ft.	— —	Hours	— — M bd. ft.	— —
Cold-decked settings:						
1R	45	48.8	1.08	37	47.7	1.29
5R	33.5	34.9	1.04	28	31.0	1.11
7R	61.5	38.3	0.62	35	36.9	1.05
Total	140.0	122.0	0.87	100	115.6	1.16
Hot-loaded setting:						
3R	59	97.6	1.65	69	97.0	1.41

[1] Includes board-foot equivalent of pulpwood.

Table 12.—Time for changing yarding roads and corner blocks, by type of setting, in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Type and setting number	Area	Volume yarded	Road changes		Corner block changes		Road changes per million board feet yarded		Corner block changes per million board feet yarded	
			Number	Average time	Number	Average time	Number	Time	Number	Time
	Acres	M bd. ft.		Minutes		Minutes		Hours		Hours
Clean-logged settings:										
2	11.4	642.4	18	11.5	6	16.6	28	5	9	2
4	10.7	595.9	21	11.5	4	16.6	35	7	7	2
6	14.0	618.8	60	11.5	9	16.6	97	19	15	4
Total	36.1	1,857.1	99	11.5	19	16.6	53	10	10	3
Relogged settings:										
Main logging:										
1	7.6	336.8	35	11.5	6	16.6	104	20	18	5
3	11.4	608.3	42	11.5	7	16.6	69	13	12	3
5	5.7	204.2	13	11.5	3	16.6	63	12	15	4
Total	24.7	1,149.3	90	11.5	16	16.6	73	15	14	4
Relogging:										
1	7.6	48.8	30	13.2	5	23.3	615	135	102	40
3	11.4	97.6	35	13.2	9	23.3	359	79	92	36
5	5.7	34.9	14	13.2	2	23.3	401	88	58	22
7	12.3	38.3	35	13.2	10	23.3	914	201	261	101
Total	37.0	219.6	114	13.2	26	23.3	519	114	118	46

Table 13.—Yarding cost summary, by type of logging, in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Item	Clean logging and first-stage logging		Relogging	
	Per day	Per hour	Per day	Per hour
	Dollars			
Yarder, 3-drum crawler unit:[1]				
Depreciation @ 15,000 hours	16.08	--	11.36	--
Interest, 6 percent of average investment	4.60	--	3.25	--
Fuel and lubrication	7.67	--	5.97	--
Repairs, 50 percent of depreciation	8.04	--	5.68	--
Taxes, 2 percent of average investment	1.53	--	1.08	--
Subtotal	37.92	4.74	27.34	3.42
Labor:				
7-man crew	144.08	--	--	--
5-man crew	--	--	104.20	--
Payroll overhead (22 percent)	31.70	--	22.92	--
Subtotal	175.78	21.97	127.12	15.89
Wire rope: [2]				
1,000 feet, 1-1/8-inch main line	2.89	--	--	--
1,000 feet, 1-inch main line	--	--	2.33	--
3,000 feet, 5/8-inch haulback	3.20	--	--	--
3,000-feet, 1/2-inch haulback	--	--	3.00	--
3,000-feet, 3/8-inch straw line	.78	--	--	--
3,000 feet, 5/16-inch straw line	--	--	.69	--
Straps	.42	--	.42	--
Chokers, 7/8-inch	4.26	--	--	--
Chokers, 3/4-inch	--	--	1.64	--
Guy lines	1.20	--	.86	--
Subtotal	12.75	1.59	8.94	1.12
Blocks:				
Butt rigging, shackles, fire tools, fuel tank, sled, signal unit, powersaw	2.04	.26	1.93	.24
Total yarding cost	228.49	28.56	165.33	20.67

[1] Clean logging used a 235-horsepower torque converter crawler tractor, estimated delivered price, new, $42,700. Estimated used price (one-third of new or $14,233) plus 3-drum yarding winch ($19,225) minus 10-percent salvage value = $30,112, amount to be depreciated.

Relogging used a 125-horsepower crawler tractor, estimated delivered price, new, $30,815. Estimated used price (one-third of new or $10,272) plus 3-drum yarding winch ($13,350) minus 10-percent salvage value = $21,260, amount to be depreciated.

All calculations are based on 240 operating days per year.

[2] Estimated life of main and haulback lines is 9 million board feet or 225 days (1,800 hours) at 40,000 board feet per day. Estimated life of straw line is approximately 2 years (480 days); straps, approximately 1 year (240 days). Estimated life of 7/8-inch chokers, 15 days, and 3/4-inch chokers, 30 days, with salvage of half the ferrules and hooks. Guy lines valued at half new value, with 5-year life.

Table 14.—Loading cost summary, by type of logging, in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Item	Clean logging and first-stage logging		Relogging	
	Per day	Per hour	Per day	Per hour
	Dollars			
Loader, crawler unit with heel boom and tongs:[1]				
Depreciation @ 20,000 hours	17.13	--	10.41	--
Interest, 6 percent of average investment	8.01		4.86	--
Fuel and lubrication	8.00		6.80	--
Repairs, 25 percent of depreciation	4.28	--	2.60	--
Cable replacement, every 20 days	2.69	--	1.58	--
Taxes, 2 percent of average investment	2.67		1.62	--
Subtotal	42.78	5.34	27.87	3.48
Labor:				
3-man crew	69.68	--	69.68	--
Payroll overhead (22 percent)	15.33	--	15.33	--
Subtotal	85.01	10.63	85.01	10.63
Total loading cost	127.79	15.97	112.88	14.11

[1] Clean logging used a 1-yard crawler unit, estimated delivered price new, $53,000. $53,000 minus 20-percent salvage value plus estimated cost of fuel tank and radio = $42,830, amount to be depreciated.

Relogging used a 3/4-yard crawler unit, estimated delivered price new, $32,000. $32,000 minus 20-percent salvage value plus estimated cost of fuel tank and radio = $26,030, amount to be depreciated.

All calculations are based on 240 operating days per year.

Table 15.—Hauling cost summary in operations in 110-year-old western hemlock near Cosmopolis, Wash., 1961

Item	Miles	Unit cost	Total cost per thousand board feet
		Dollars	
Road class A, paved, not over 6-percent grade	12.3	0.155	1.91
Road class A-1, continuously maintained gravel, not over 6-percent grade	4.8	.165	.79
Road class B, continuously maintained gravel over 6-percent grade	.5	.220	.11
Basic rate per piece (average 43 pieces)		.065	2.80
Basic rate per thousand board feet	--	--	1.82
Gross cost per thousand board feet	--	--	7.43
Net cost per thousand board feet, with estimated 5-percent defect	--	--	7.82
Net cost per thousand board feet, with estimated 12-percent profit and risk removed	--	--	6.88

Source: Washington Utilities and Transportation Commission rates, adjusted for log defect and profit risk.

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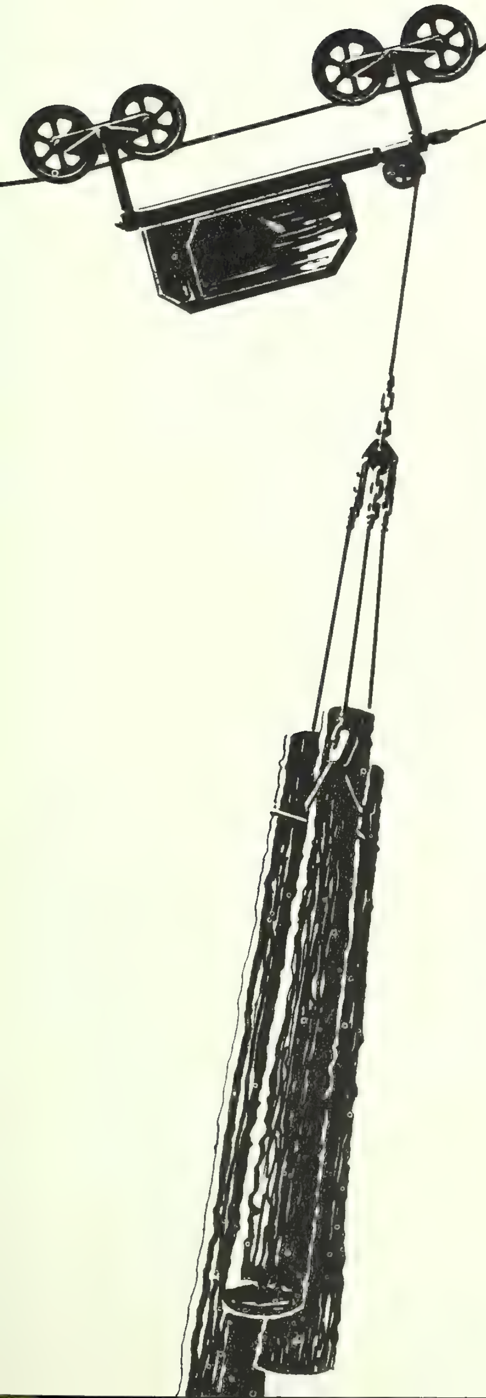

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Introduction

Soil and watershed values are of critical concern to forest-land managers in many parts of the Pacific Northwest where steep slopes and potentially unstable soils may preclude logging by conventional methods. Ruth[1] estimated from 1.5 to 3.8 million acres of commercial forest land on the National Forests of Oregon and Washington that should be managed with special effort to minimize soil disturbance. Similar problem areas are found on other ownerships. In an effort to log these economically and carefully, such recent developments as gravity-operated skyline systems, helicopters, and balloons have been tried. In each instance, the main purpose has been to reduce the amount of road construction needed and to minimize soil disturbance during yarding. This study was undertaken to determine the economy of a skyline logging system being used on a problem area in the coastal forests of Oregon.

The chief feature of skyline yarding systems is that logs are yarded laterally to a suspended cable and then transported longitudinally along the cable to a landing. Typically, the skyline is located on a slope, with the logs lowered down the skyline by gravity.[2] Total length of the skyline may be as much as 1 mile. Thus, in comparison with conventional high-lead yarding where yarding distances are generally under 1,000 feet, skyline yarding not only minimizes soil disturbance but, even more important, eliminates much secondary and spur-road construction.

This study of costs has revealed the especial need for advance engineering and planning and detailed estimating to reduce or hold down the high cost of rigging, moving time, and nonproductive time associated with skyline logging systems.

Therefore, this report makes an analysis of engineering and cost information that should be helpful to timber sale administrators and logging managers in achieving efficient operation and favorable results.

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[1] Ruth, Robert H. It's time to look at yarding problems on steep slopes. U. S. Forest Serv., Pac. NW. Forest & Range Expt. Sta. Res. Note 185, 4 pp., illus. 1960.

[2] [illegible] ered in this report.

The Study Area

This study was conducted in the undeveloped Fall Creek drainage of the Cascade Head Experimental Forest near Otis, Oregon. The spruce and hemlock trees were predominantly 115 years but occasionally 200 or more years old. The broken terrain of the area is typical of the coastal ranges of western Oregon. Elevation varies from 160 to 1,700 feet above sea level. Timber volumes ranged from 50,000 to 90,000 board feet per acre. Yarding of the study area was done from January 1960 to February 1964.

An experimental sale, consisting of approximately 20 million board feet, was laid out in five cutting units. A main haul road was constructed up the drainage to the bottom of each unit. Also, short administrative roads or "tote roads" were constructed to the top of each unit. These tote roads were negotiable by track vehicle only and were used for moving the snubbing machine, or yarder, to the top of each unit and providing access for men and material. This was in contrast to the more typical high-lead logging system with hauling roads at the top of the unit.

Length of the skyline road (cableway) varied from 2,000 to 4,400 feet. The number of intermediate supports on any one skyline road varied from none to two.

Unit 28 was logged first, with four single-span skyline roads approximately 2,300 feet long. Unit 31 was logged with three multispan skyline roads. One road in this unit was yarded uphill to test the equipment for uphill use. The production rate uphill was not significantly different from gravity operation.

The back slope of unit 32 was yarded by high lead using a separate yarder, and the logs were then swung to the landing by the radio-controlled carriage on the skyline (fig. 1). Unit 37A was yarded with three 2,100-foot single-span skyline roads, with the snubbing machine located near the landing. The snubbing line was rigged similarly to the haulback line on a high lead. Operation with the snubbing machine (yarder) located at the landing proved to be quite satisfactory. Unit 37B was the most difficult unit of the five to yard. Broken terrain and lack of suitable intermediate support trees required the use of a cross or intermediate support skyline. This method of rigging will be discussed later in this paper.

A detailed time study of operations was made on cutting unit 32. Cutting-unit design and field engineering procedures were developed during layout of units 32 and 37B.

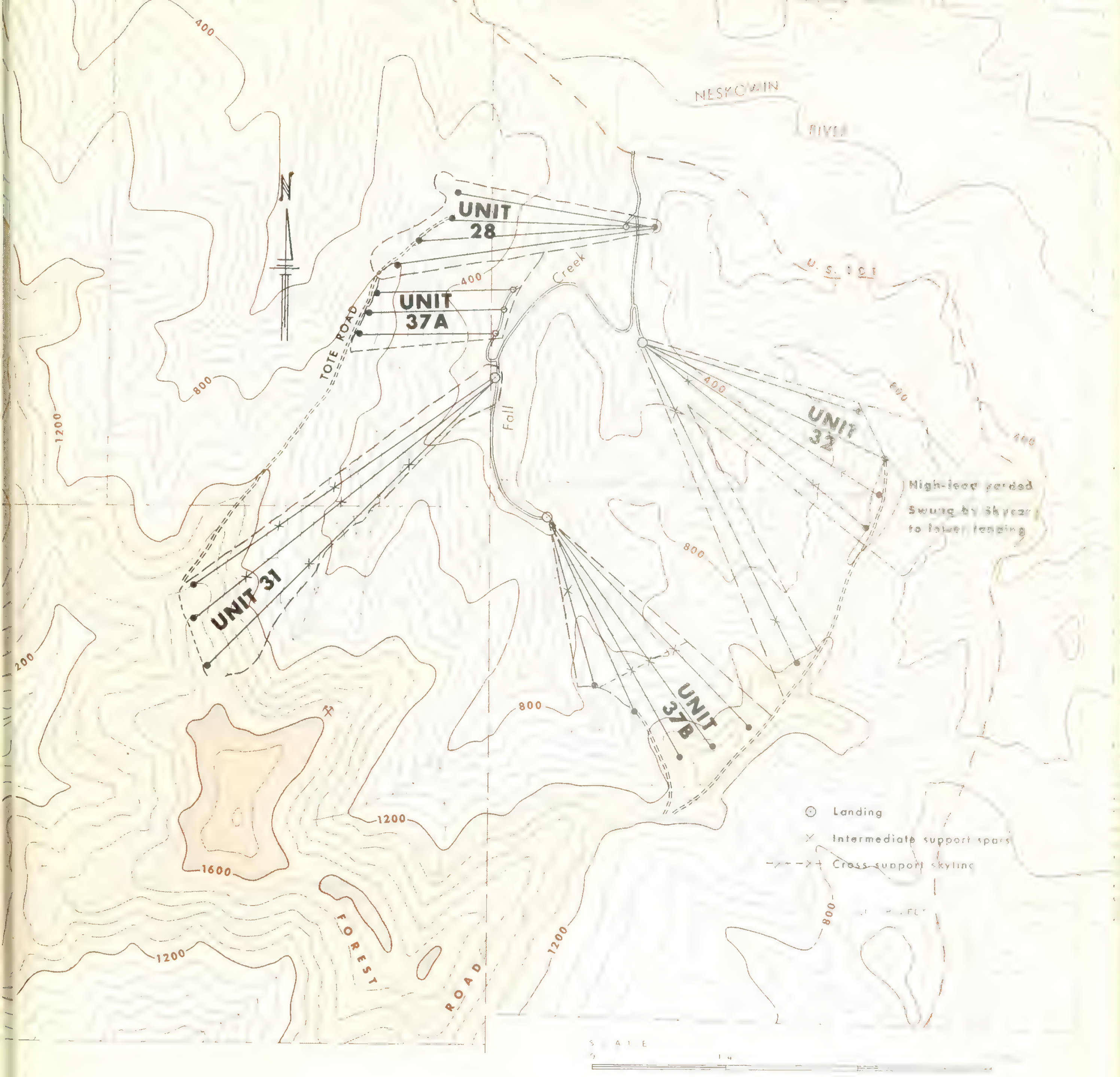


Figure 1.—Topographic map of experimental sale area showing skyline cutting units and road network for the Fall Creek drainage of the Cascade Head Experimental Forest.

Description of Equipment and its Operation

In addition to the skyline itself (5,000 feet of 1-3/4-inch wire rope), the chief pieces of equipment used in this operation consisted of a Skagit Model RCC-20 Skycar carriage and a 335-horsepower BX-185 yarder, or snubbing machine, equipped with a three-stage torque converter, two-speed clutch (figs. 2A and 2B), and hydrotarder.

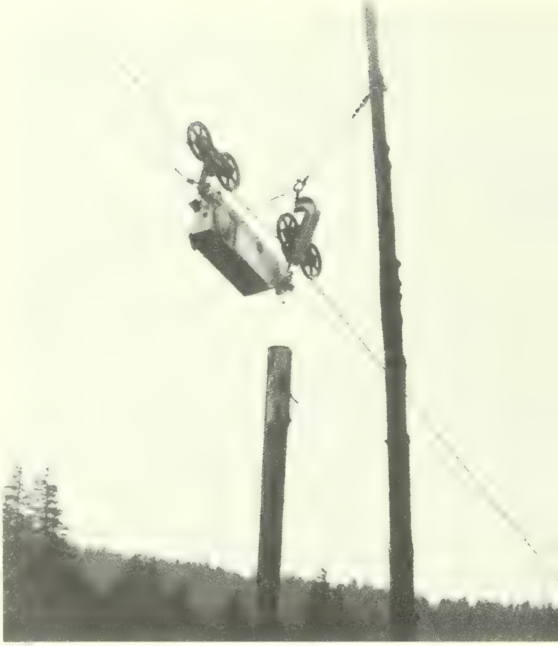
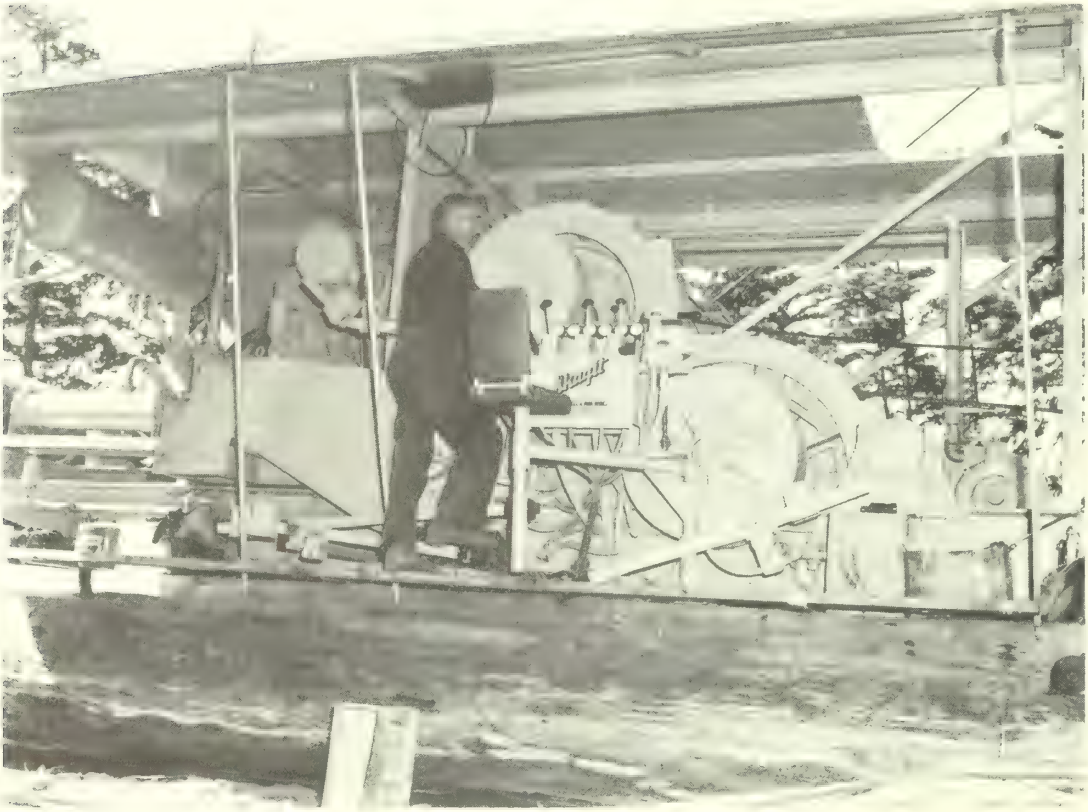


Figure 2

A. A loaded RCC-20 Skycar passing an intermediate support tree and jack.

B. Side view of snubbing machine (yarder) showing controls and main drums.



The Skagit Model RCC-20 Skycar, which rides on the main skyline, incorporates a 95-horsepower GMC Model 4-53 diesel engine driving through a twin disc, three-stage, dynamic breaking torque converter. Power is transmitted from the torque converter to the drum set through a propeller shaft. The reversible, load-line drum is engaged by air-operated multiple clutches. The RCC-20 Skycar is suspended from the skyline by an open-side carriage; e.g., the Skycar is permitted to travel past support jacks, which suspend the main skyline at intermediate points.

The Skycar suspension system has four sheaves, 36 inches in diameter, which ride on the main skyline. Suspension from the four sheaves is by a patented swivel system which allows the Skycar to remain in a relatively perpendicular position while yarding laterally to the skyline.

The diesel engine runs at idle speed until accelerated by radio impulse, when the skidding drum is engaged for paying out line or for skidding the turn to the carriage. The skidding drum has a capacity of 400 feet of 7/8-inch-diameter wire rope, which permits lateral skidding of approximately 300 feet. The no-load speed for paying out slack is 400 feet per minute; for paying in, it is 319 feet per minute, with a stall pull of 40,000 pounds. Line speeds and pulls are based on average drum conditions. The designed weight-carrying capacity of the Skycar is 40,000 pounds. Gross weight of the RCC-20, including wire rope, fuel, and water, is 8,140 pounds.[3]

Snubbing Machine

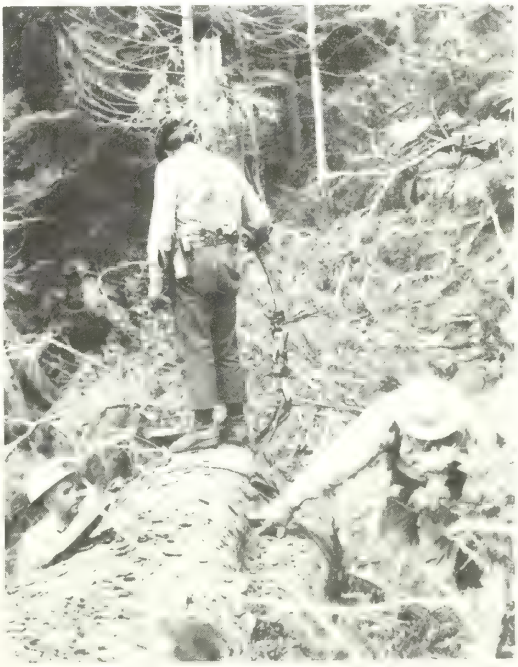
The snubbing machine has three drums. One holds 4,400 feet of 1-inch snubbing line; another, 5,700 feet of 3/4-inch haulback line (used for rigging intermediate support spars and for tensioning the skyline); and the third, 5,000 feet of 7/16-inch straw line. The snubbing machine is equipped with a hydrotarder which is used to brake the speed of the loaded carriage down the skyline. Line speeds and pulls, based on average drum conditions, are as follows:

	MAIN DRUM		HAULBACK DRUM	
	SPEED (ft./min.)	PULL (lbs.)	SPEED (ft./min.)	PULL (lbs.)
HIGH RANGE:				
High	775	7,150	2,450	2,260
Low	352	15,700	1,130	5,000
LOW RANGE:				
High	202	29,400	635	9,350
Low	92	64,000	290	20,400

Radio Control System

An operator controls the Skycar with a small radio transmitter, called a Talkie-Tooter, which has a channel for the carriage engine and skidding-line drum (fig. 3). The engine is controlled at three possible speeds when it pulls the skidding line laterally or skids a turn to the skyline.

Figure 3.—Talkie-Tooter transmitter is attached to the belt of the operator (shown near the left elbow of the workman in the center of the photo).



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[3] Data from Skagit Corporation.

The Talkie-Tooter has a control selector on the end of the handle with four signal positions: up, down, stop, and whistle. Two features are built into the Talkie-Tooter which help insure personnel safety. The selector must be moved through "stop" each time the up or down cycle is used. A second safety feature is a two-position, squeeze handle, signal switch. The switch has both a warmup and a signal position to complete a signal cycle. A partial squeeze of the handle activates only the warmup switch. This feature helps insure that a signal will not be transmitted accidentally by bumping the handle. When the carriage is at rest and activation of the load-line drum is not desired, the selector switch is kept at "stop." The Talkie-Tooter also transmits voice signals to receivers on the Skycar and yarder.

Three Talkie-Tooter transmitters are used on a radio-controlled skyline logging system. The unhooker (chaser) at the landing and the rigging slinger in charge of the choker setters each has a transmitter. A spare transmitter is kept at the snubbing machine to be used in operating the carriage when supplies are sent up the skyline to the snubbing machine.

The following audible signals were used:

— —	Ahead on snubber line	Slow (power)
— — —	Ahead on snubber line	Fast (power)
Voice signal	Ahead on snubber line	Slow (gravity)
— — — —	Ahead on snubber line	Fast (gravity)
—	Stop any moving line	
-- -- --	Lower skyline	
-- -- -- -	Raise skyline	

Each turn of logs involves the following sequence in use of the Talkie-Tooter. As the empty carriage approaches the area of loading, the operator moves the selector from "stop" to "whistle," signaling the snubbing machine operator to stop the carriage. The selector is then moved to "down" and the skidding line is lowered and pulled laterally to the turn of logs. When the skidding line is near the logs, with the selector at "stop," the signal switch is pressed, stopping the yarding drum in the carriage. The selector is moved to "up" when the turn is hooked and the crew is in the clear. The carriage drum is activated, skidding the logs to the skyline. The selector is then moved to "stop" and the skidding drum is stopped when the turn is under the carriage. The selector switch is then moved to "whistle," and a whistle signal is blown to indicate that the loaded carriage is to be lowered along the skyline to the landing. The operator then moves the selector to "stop" until the carriage returns.

When the carriage nears the landing, the chaser moves the selector of his transmitter from "stop" to "down" and lowers the turn while the carriage is moving. Markings on the snubber line indicate to the snubbing-machine operator when the carriage has reached the landing.

After activating the down cycle, the chaser moves the selector to "stop" and stops the skidding drum when the turn is on the landing. After chokers are unhooked, he moves the selector to "up," and the skidding line and chokers are pulled to the carriage. As the butt-hook and chokers near the carriage, the drum is stopped and the signal made to return the carriage to the working area. The chaser then switches the selector to "stop" and waits for the next turn.

The Operation in Brief

A skyline yarding system can be described as a system that can yard logs laterally to a suspended cable as well as transport these logs longitudinally along the cable to a landing.

A complete cycle of operation for a skyline-crane yarding system consists of six phases. In this paper, they will be referred to as T_1, T_2, T_3, T_4, T , and T_6.

Phase T_1 is the time required to move the carriage from the landing along the skyline to the point of loading.

Phase T_2 is the time required to pull the skidding line laterally from the carriage.

Phase T_3 is the time required to hook a turn of three logs to the skidding line.

Phase T_4 is the time required to skid a turn of logs laterally to the skyline.

Phase T_5 is the time required to move the loaded carriage along the skyline to the landing.

Phase T_6 is the time required to unhook a turn of logs at the landing.

Figure 4 shows a plan view of a cycle of operation for a skyline yarding system.

Figure 4.—Plan view of a skyline yarding cycle.

Layout and Design

This study involved much first-hand observation of cutting-unit design and layout. Also, other skyline systems were visited in Oregon, Washington, and British Columbia. In this paper, cutting-unit shapes and skyline layout are specified for several topographic conditions, special rigging situations are identified, and the necessary field and office work is described for a cutting unit and for an extensive drainage area.

Skyline Cutting-Unit Design

Skyline cutting units may be rectangular in design, with parallel skyline roads, or fan shaped, with skyline roads radiating from a single point (fig. 5). The rectangular shape is more desirable. For example, compare the two units illustrated:

	Fan-shaped road	Rectangular road
External distance	3,000 feet	3,000 feet
Average yarding distance	3,000 X 0.5 = 1,500 feet	3,000 X 0.667[1] = 2,001 feet
Area served by each skyline road	20.66 acres	12.40 acres[2]

[1] Average yarding distance factor.

[2] Based on the area of a triangle 3,000 feet long with a base of 360 feet.

Note that the same length of skyline serves 8.26 more acres in the rectangular shape than in the fan shape, with a shorter average yarding distance. However, terrain and the costs of moving and rigging at the landing may make the fan shape preferable.

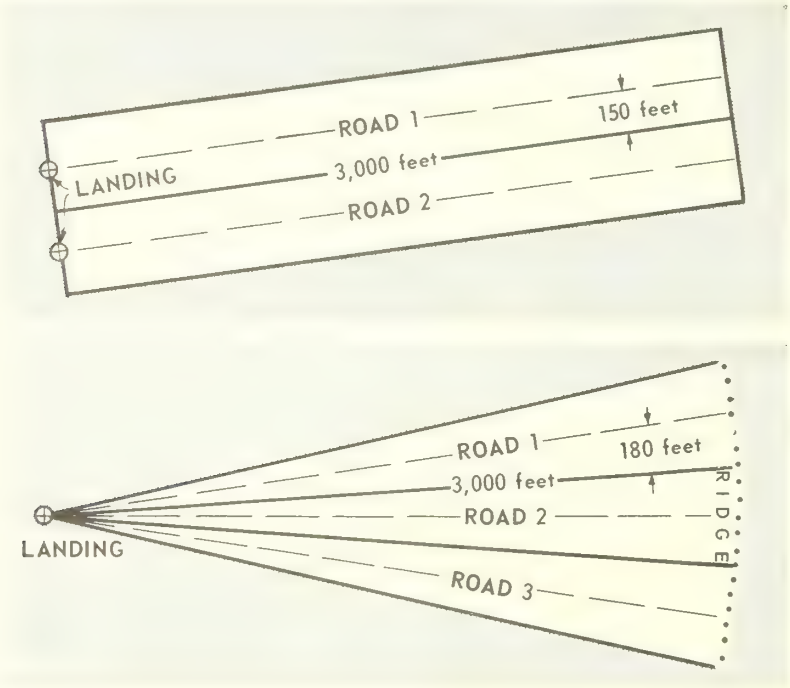
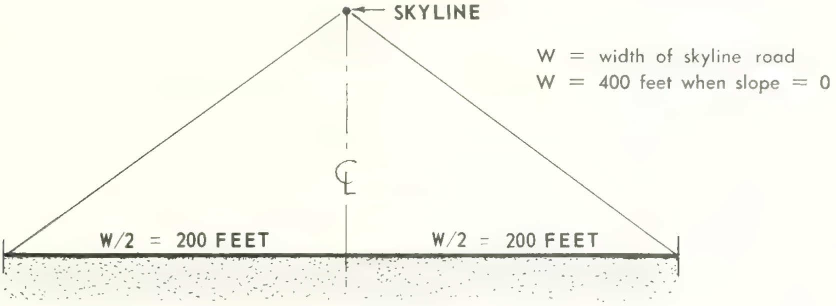


Figure 5.—Rectangular cutting unit, with two parallel skyline roads, and fan-shaped cutting unit, with three skyline roads radiating from one landing.

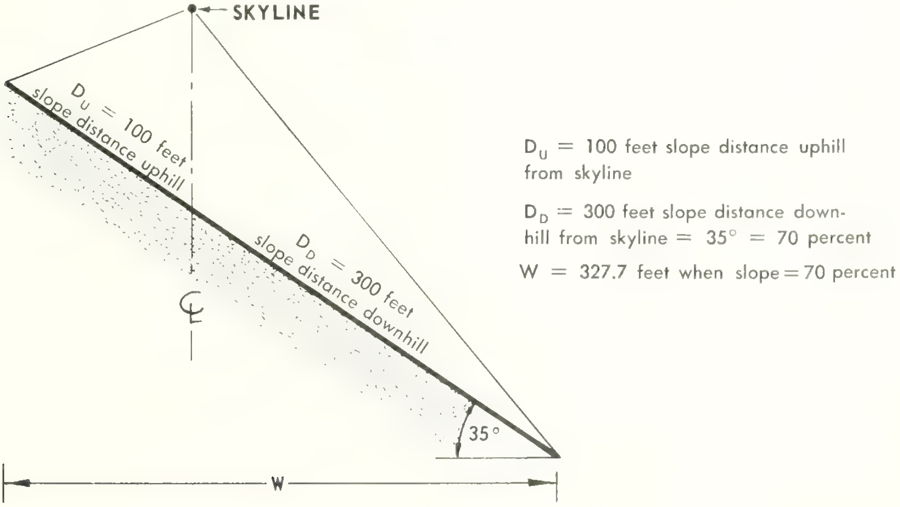
Effect of Side Slope Under the Skyline

Skylines are frequently set up with the skyline following the contour; thus, the ground slope laterally under the skyline may vary from 0 to 100 percent or more. A steep side slope sharply restricts the distance the skidding line can be pulled uphill, and, although the line can be pulled farther downhill, the total width of the skyline road is markedly less. This, in effect, reduces the area served by each skyline road.

For example, in this study the rigging crew was able to pull the skidding line only 100 feet slope-distance uphill from the skyline, but could pull it 300 feet downhill on a 70-percent side slope. If a skyline road is 4,500 feet long with no side slope, it would cover 41.32 acres; a strip with 70-percent side slope would cover 33.85 acres, a difference of 7.47 acres (fig. 6).

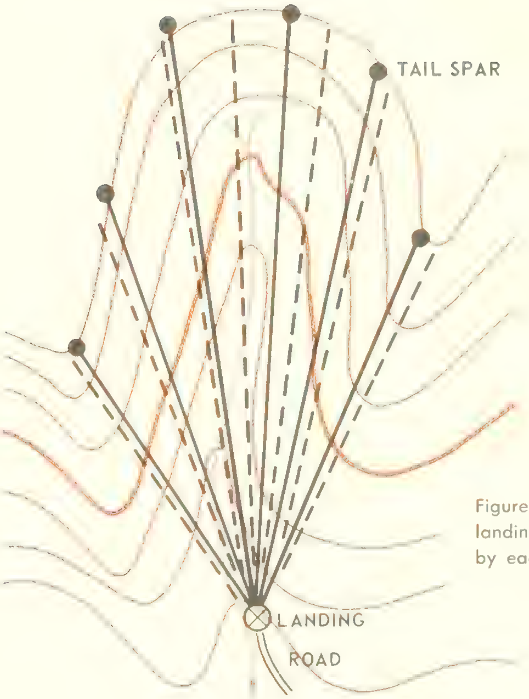


Cross section of a skyline with a lateral slope under the skyline of 0 percent.


SKYLINE
D_U = 100 feet slope distance uphill
D_D = 300 feet slope distance downhill
℄
35°
W
D_U = 100 feet slope distance uphill from skyline
D_D = 300 feet slope distance downhill from skyline = 35° = 70 percent
W = 327.7 feet when slope = 70 percent

Cross section of skyline with a lateral slope of 70 percent.

Figure 6.—Example of effect of side slope under the skyline.

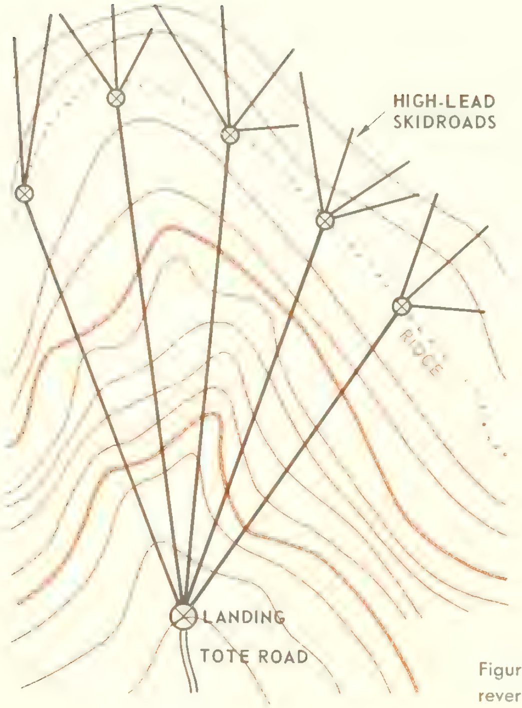


Fan-Shaped Unit

A fan-shaped unit is generally used when a cutting unit is laid out in a drainage head (fig. 7). A single spar is used at the landing and the skyline roads radiate to tail spars spaced along the outer edge of the unit. Note that each skyline is not in the center of the road or area to be logged, because the weight of the butt-hook and chokers cannot be pulled by hand as far uphill as on the level or downhill.

Fan-shaped units in a drainage head may be particularly troublesome in this respect, due to the amount of sloping ground frequently encountered.

Figure 7.—A fan-shaped unit with skyline roads radiating from a landing. Solid lines are skylines and dashed lines indicate area served by each skyline. Contour lines are also shown.



Fan-Shaped Unit with High-Lead Yarding from the Reverse Slope

A combination of high-lead yarding with a skyline crane swing to a landing may often be practical (fig. 8). This may require a combination yarder-snubbing machine at the top of the unit. Such a machine could be used to high lead and cold deck at the tail spar as well as serve as a skyline crane snubbing machine. In cases where large volumes are available, it may be practical to move a separate high-lead yarder to the tail tree and use a hot-deck swing operation. Should the capacity of the skyline crane be greater than the high-lead machine, the skyline crane can work as a yarding unit on the skyline road until a sufficient cold deck is available for a maximum capacity swing. Alternating skyline yarding and swinging will maximize the production of the logging system.

Figure 8.—Fan-shaped skyline unit with high-lead yarding from the reverse slope.

Rectangular Unit

Rectangular units are usually laid out on slopes having a flat face and a gradient of 30 percent or greater (fig. 9). The rigging consists of a head spar, a tail spar, intermediate supports as required, and a landing.

The unit is laid out perpendicularly to the contour of the slope, giving a side slope across the contour or nearly so.

Rectangular cutting units, as shown in figure 10, represent the most desirable design that can be incorporated into a skyline logging plan. Average lateral and longitudinal distances are one-half the external distances, thereby providing the maximum area to be logged by each skyline road.

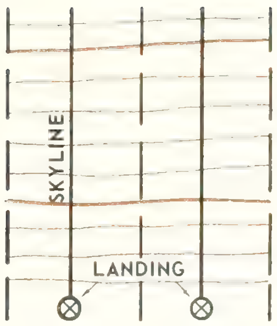
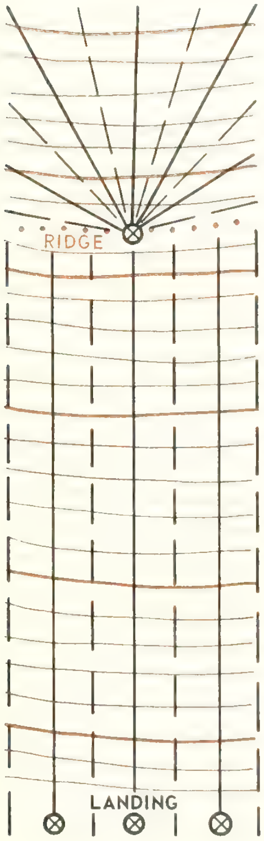


Figure 9
A rectangular cutting-unit design on a long, continuous slope face.

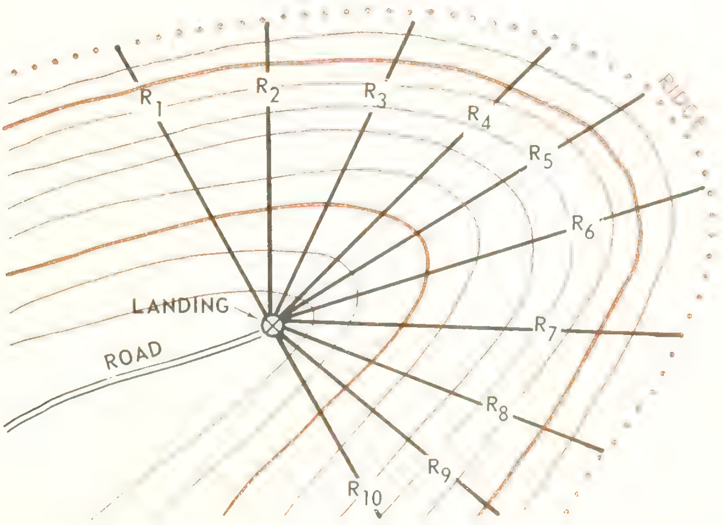
Figure 10
A rectangular unit with a high-lead swing from a reverse slope.



Half-Circle Skyline Unit

Large bowl-shaped drainage heads, or valley heads, present topographic features adaptable to a half-circle design (fig. 11). Large units result from this type of design, and alternate cutting of the skyline roads would encourage more natural regeneration.

Figure 11.—Topographic situation suited for half-circle cutting-unit design.

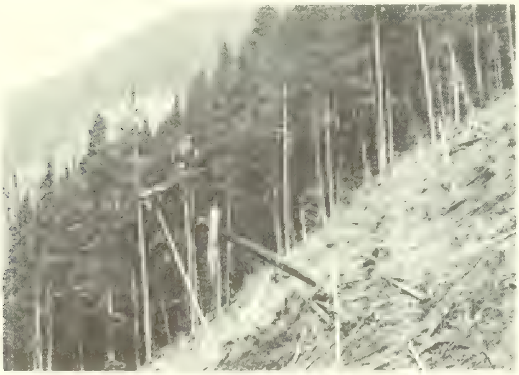


Dragging

Dragging can occur if there is a large amount of deflection in the skyline. This should be avoided by careful preparation of skyline profiles and by proper design of cutting units (fig. 12). Dragging increases cycle time and puts a severe stress on the equipment when the logs swing free after a period of dragging.

Logs, hanging in a perpendicular position under the descending carriage, often strike the ground ahead of the carriage. When this occurs, there may be damage if the carriage strikes the elevated ends of the logs as it passes over the dragging point.

Figure 12.—Turn of logs dragging during downhill swing. A number of logs striking the same spot can cause undesirable gouging of the soil.



Slope Condition Profiles

Three basic types of ground profile that may be encountered in the design of a skyline crane cutting unit are concave, convex, and constant.

CONCAVE PROFILES.—Concave profiles can often accommodate a free span (fig. 13). However, figure 14 shows a concave slope condition where intermediate supports are required. Such conditions may present a problem of deflection when one subspan is loaded. When the loaded carriage is in one subspan, deflection is drawn from the remaining three subspans, possibly causing the logs to drag if the ground profile will not accommodate the deflection in the loaded span. Such slope conditions should be avoided when gravity-operated skyline logging systems are being designed.

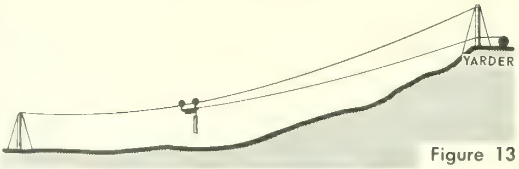


Figure 13

Single-span skyline on a concave profile that will allow passage of a loaded carriage clear of the ground.

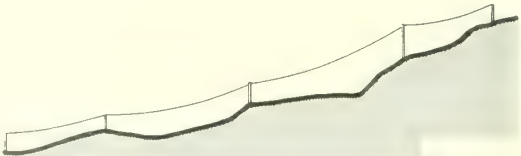


Figure 14

Concave profile that requires the use of support trees.

CONCAVE PROFILE CROSSING RIDGE LINE. —A depression in a profile, as in subspan 2 of figure 15, caused by crossing of a ridge line, should be avoided in cutting-unit design because a large sag in the snubbing line develops in subspan 2, making the speed of the carriage at the top of subspan 1 difficult to control. In this case, the velocity of the carriage increases rapidly after passing the support. Complete control of the carriage is not regained until the slack is pulled from the snubbing line in subspan 2. Excessive strain results on the rigging, carriage, snubbing line, skyline, and snubbing machine. The added height above ground of the skyline in subspan 2 increases the time to perform the lateral-out (T_2) and lateral-in (T_4) phases of the logging cycle. Cutting units should be laid out so as to avoid such conditions.

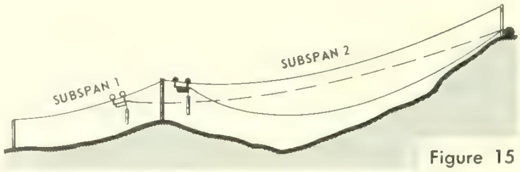


Figure 15

Skyline profile showing carriage crossing a ridge line in the unit.

CONVEX PROFILE.—A convex profile requires the use of intermediate supports (fig. 16), but locating these supports and tensioning of the skyline are less complex problems than found with other slopes. In this case, tensioning the skyline exerts a downward force on the skyline jack instead of lifting it, as might occur in a concave slope condition. Proper spacing of the supports and correct tensioning of the skyline are essential to reduce the possibility of dragging in the various subspans.

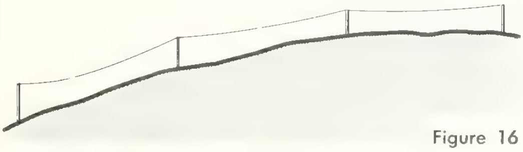


Figure 16

Convex profile with intermediate supports.

CONSTANT PROFILE.—A constant profile presents a problem similar to that of a concave profile (fig. 17). The possibility exists that one of the supports will be shorter than the others (fig. 18). Under this condition, when the loaded carriage is in subspan 1, deflection is drawn from subspans 2 and 3, raising the skyline above the short intermediate support and putting a severe stress on the skyline jack, possibly inverting it.

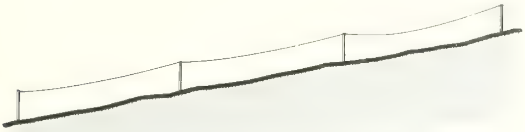


Figure 17

Constant profile with support trees.

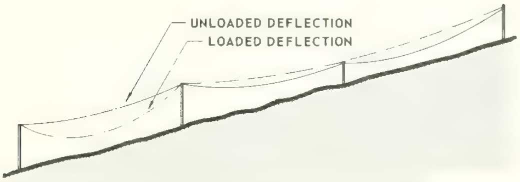


Figure 18

A constant profile with one short intermediate support spar.

Intermediate Support Spars

When terrain features are such that a single-span skyline cannot be used, the skyline must be held clear of the ground by intermediate supports to allow the carriage and load to pass without contacting the ground. Intermediate support spars fall into three classes: standing, leaned, and raised.

Standing intermediate support spars are trees directly alined with the skyline and can be rigged in place. When rigged, this type of support resembles the conventional high-lead spar tree in appearance. The skyline jack is held in position by a reinforced guy line.

Leaned intermediate supports are trees which are cut on the stump and leaned to facilitate alinement with the skyline. The base of the tree is tied back to keep it on the stump (fig. 19).

Raised intermediate support spars are used when a support is needed and suitable trees are not available. Raising an intermediate support spar requires a portable winch.

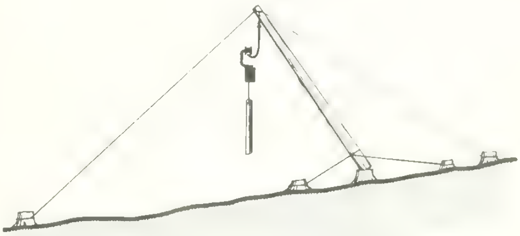


Figure 19

Cross-section view of a leaned intermediate support spar showing carriage, guy lines, and spar.

Cross Support Skylines

The cross support skyline is a cable tensioned across a cutting unit to high points on both sides of the unit (fig. 20). It supports the main skyline in the same manner as an intermediate support spar. This type is used when terrain features make the use of support spars impractical.

Drainage heads with fan-shaped units are best suited to use of a cross support skyline.

The major portion of the rigging for a unit can be accomplished before actual logging begins. Moving the skyline or road changing is simplified when cross support skylines are used.

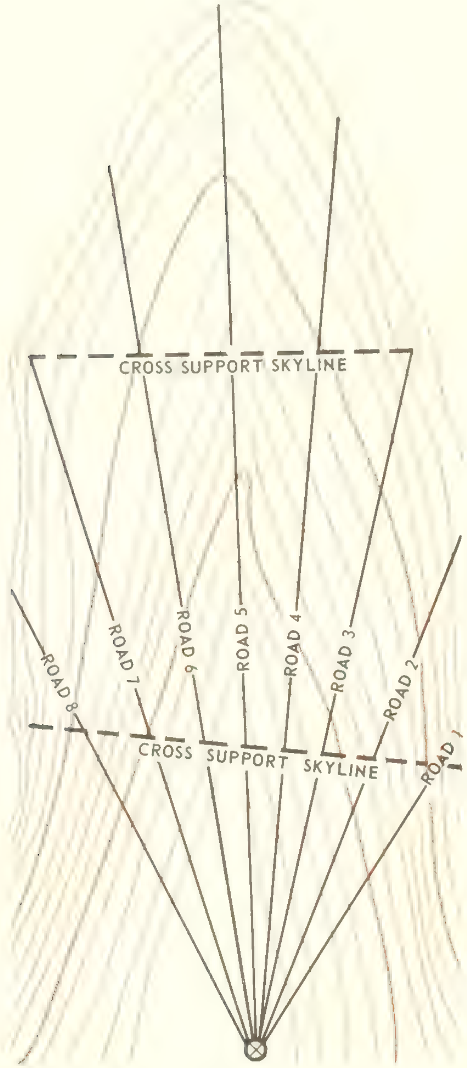


Figure 20
Drainage head with fan-shaped layout and cross support skylines.

Special Rigging Situations

GROUND RIGGING IN PLACE OF HEAD OR TAIL SPARS.—When terrain allows use of tail-hold anchors to replace spars, erecting the skyline can be accomplished with a minimum of effort (fig. 21).

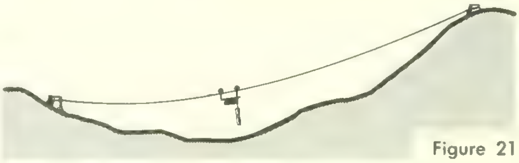


Figure 21
Single-span skyline rigged with tail-hold anchors.

OPERATING LINE ROLLERS.—Line rollers may be placed under the skyline on terrain that would be abrasive to the snubbing line. The roller is a sheave mounted in a steel frame which holds the line clear of the ground (fig. 22).

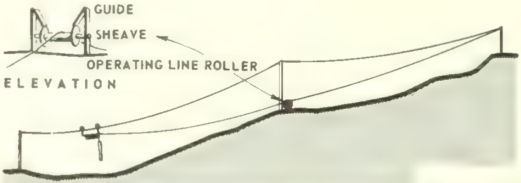


Figure 22
Operating line roller placed to reduce abrasion of the snubbing line.

SKYLINE JACKS.—The skyline jack is a J-shaped device, suspended from an intermediate support spar or cross support skyline, and allows an open-sided carriage to travel along the skyline (fig. 23).

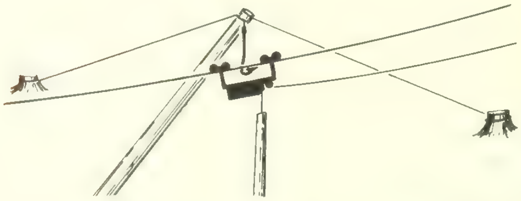


Figure 23
Longitudinal cross section of open-side carriage passing a skyline jack.

TAIL-HOLD ANCHORS.—The anchor for a skyline must resist the maximum load supported by the skyline. Anchors at the bottom of a unit are generally easier to rig than at the top because of less tension and because the stumps are generally larger. If a large stump is not available, a series of small stumps may be rigged to make a suitable anchor (fig. 24). Anchoring at the top of a unit, where stumps are usually smaller and where tension is greatest, presents a more difficult rigging situation.

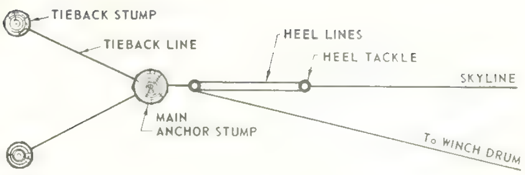


Figure 24.—Plan view of rigging a main anchor stump with tieback stumps.

Usually, a series of stumps is required to make a satisfactory anchor at the upper end of a skyline. Figure 25 shows a method for rigging an anchor with 8 stumps and tiebacks to an additional 16 stumps. Placing single-part blocks back to back equalizes the strain on each stump.

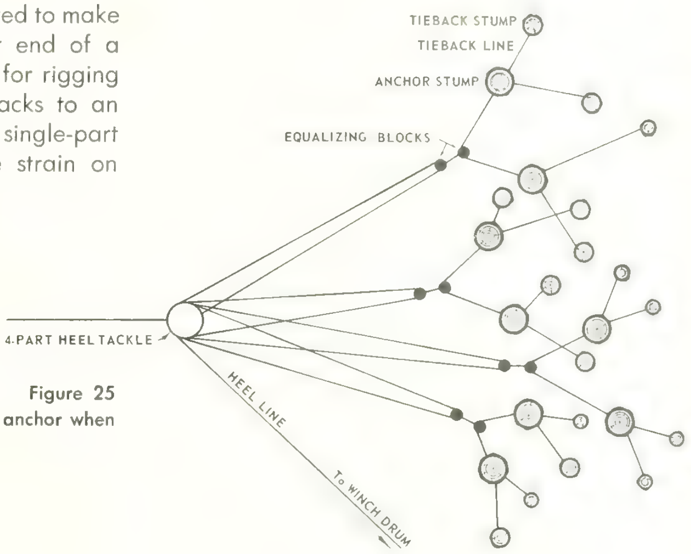
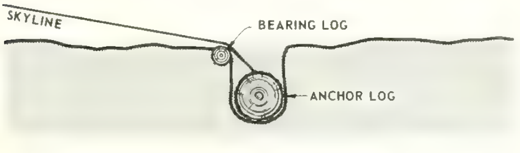


Figure 25
Plan view of a method of rigging a tail-hold anchor when small anchor stumps are used.

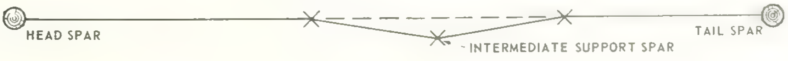
"DEADMAN" ANCHORS.—Where suitable stumps are not available, a "deadman" may be used as a tail-hold anchor. Various methods for constructing deadmen can be used; however, a buried log is the most practical (fig. 26).

Figure 26.—Cross-section view of a "deadman" anchor.



ALINEMENT OF SKYLINES.—Skyline supports must be alined between the head and tail spars (fig. 27). Lateral deflection in the skyline, caused by the support jacks being out of alinement, increases wear on the skyline and reduces the speed of the carriage passing an intermediate support. If a skyline jack is severely out of alinement, it could cause derailment of the carriage or damage the safety device which keeps the carriage on the skyline.

Figure 27.—Aerial perspective of a misalined multispan skyline.



Skyline Deflection and Tension

Deflection and tension in a suspended cable can be calculated by using formulas taken from wire rope and engineering handbooks. These calculations are routine for single spans but very complex for multispan skylines. No attempt will be made to cover this subject in this paper.

To insure proper working loads, some operators have placed load cells in the skyline near the upper end so that tension can be accurately measured. However, there is no question that efficient design of a skyline logging system requires the determination of tension and dedeflection of the loaded skyline.

Field Engineering

Prior to starting actual field work, the designer of the operation should make a reconnaissance of the cutting-unit perimeter, flagging the line to be run, marking suitable head and tail spars, and marking suitable landing locations at the bottom of the unit.

The next step is to run a closed traverse around the unit, including the head and tail spars and suitable tail-hold anchors. This traverse will give horizontal and vertical control of the unit. The traverse can be run as a meander line, avoiding undue delay by offsetting around obstacles and brush.

The initial traverse will give angular control, as well as vertical and horizontal distance, that is necessary when the skyline road profiles are traversed.

The initial traverse can be plotted by use of bearings and distances or latitudes and departures. The bearing of each skyline road then can be calculated or measured, depending on the accuracy desired. Traverse of a skyline profile without the perimeter survey may be a waste of time if the bearing of the line between the head and tail tree is not accurate.

A two-man crew can accomplish field engineering with a staff compass, 200-foot engineer's chain, percent Abney, and slope correction tables.

TRAVERSE OF PROFILE LINES.—Each skyline road can be traversed with the bearing obtained from the plot of the initial survey. Suitable support trees should be tied to the traverse and their d.b.h. and height should be recorded.

SIDE SLOPE NOTES.—Side slope notes recorded at each station or setup can be used to paper locate the profile ("L" line) if the traverse line misses the intended tail tree by 50 feet or less. Figure 28 illustrates the note taking for this method of traverse. These notes will be found invaluable if the profile line must be moved a short distance right or left to take advantage of more desirable terrain, taller intermediate support trees, a more suitable tail tree, or a stronger tail hold.

NOTE TAKING, STAFF-COMPASS METHOD

Station	Horizontal distance	Slope distance	Percent	Bearing	Difference in elevation	Elevation	Side Slope		Remarks
							L	R	
	(Feet)	(Feet)				(Feet)			
0 + 00						1,500	0 50	0 50	Center of landing
	124.5	130	+30	N10W	+37.3				
1 + 24.5						1,537.3	-50% 50	+50% 50	
	139.3	150	+40	N10W	+55.7				
2 + 63.8						1,593.0	-40% 50	+55% 50	
	191.6	200	-30	N10W	-57.5				
4 + 55.4						1,535.5	-30% 40	+40% 50	Support tree 36′ left D.b.h. 36″ - 110′

Figure 28.—Method of note taking for a skyline profile traverse.

The technique for making an L profile line from the traverse notes is similar to the design technique used on a forest access road. Accurate side slope notes can be the difference between an accurate L line made in the office or the rerunning of a profile in the field.

Developing a Harvest Plan for a Large Drainage

The following illustrates the use of a topographic map in making a harvest plan for a large drainage area to be logged by a gravity skyline system. In this design, the premise is that low-standard administrative roads would be constructed to the top of ridge lines separating major drainages (fig. 29).

A cutting pattern was developed to give an orderly harvest with systematic development of the main haul and administrative road system (table 1). Actual skyline logging of 4,071 acres, with an average volume per acre of 65,000 board feet, would take an estimated 9 years to complete, using six machines and crews. Details on the road systems are as follows:

Road number	Construction standard	Length
2,000	SH14	4.37 miles
2,020	SL12	1.00 mile
2,020	SL10	5.62 miles
2,022	SL10	1.40 miles
2,024	SL10	1.40 miles
2,060	SL10	2.40 miles
2,010	SL10	3.62 miles
2,030	SL10	3.15 miles
Total		22.96 miles

The data indicate that 5.37 miles of main haul road must be constructed to transport the logs to the lower edge of the harvest area. Administrative roads to the ridgetops total 17.59 miles. Charging the total administrative road cost to this area would be unrealistic, because these roads not only serve the skyline drainage but adjacent areas as well, an additional half of the skyline area would be served by this road system, and road density would be 15.19 miles of road divided by 9.54 square miles, or 1.59 miles of road per square mile. Road 2060 is considered an internal road in the skyline harvest area.

Total road construction cost would be less than that for high-lead logging, because only 5.37 total miles would be of a standard required for log hauling. The reduction in hauling costs, road maintenance, and added construction, when compared with high-lead yarding should also be considered. Silen and Gratkowski[1] found an average road density of 5.19 miles per square mile in the staggered-setting system of high-lead yarding. When average road density is compared, the skyline system reduces the amount of road needed by 5.19 minus 1.59, or 3.60 miles per square mile. The saving is even greater if only the high-standard roads are considered; this saving amounts to 5.19 minus 0.56, or 4.63 miles per square mile.

One should remember that, after a drainage has been committed to skyline harvest, it will be difficult, and in some cases economically impossible, to revert to conventional high-lead yarding because the remaining volume will not support road development costs.

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[1] Silen, Roy R., and Gratkowski, H. J. An estimate of the amount of road in the staggered-setting system of clearcutting. U. S. Forest Serv. Pac. NW. Forest & Range Expt. Sta. Res. Note 92, 4 pp. 1953.

Table 1.—Data relative to the hypothetical cutting units of figure 29.

Unit	Number of skyline roads	Average external distance	Factor	Average estimated swing	Acres	Sequence of cut	Acres per road
		Feet		Feet			
1	10	3,208	0.667	2,268	121	1	12.1
2	9	1,663	(1)	487	67	5	7.4
3	3	1,254	.500	627	31	11	10.3
4	4	1,452	.500	726	55	8	13.8
5	4	1,504	.500	752	47	17	11.7
6	3	1,584	.500	792	44	20	14.7
7	4	1,940	.500	970	52	23	13.0
8	20	2,639	.667	1,866	272	26	13.6
9	4	1,769	(1)	518	41	29	10.2
10	4	2,072	.500	1,036	60	32	15.0
11	4	2,217	.500	1,118	59	34	14.8
12	0	--	--	--	48	3	
13	4	1,914	(1)	561	55	6	13.8
14	3	4,646	.500	2,323	136	13	45.3
15	3	5,755	.500	2,878	166	15	55.3
16	3	6,864	.500	3,432	194	19	64.7
17	3	5,874	.667	4,153	119	24	39.6
18	2	5,003	.500	2,501	80	27	40.0
19	4	3,696	(1)	1,083	90	30	22.5
20	3	5,267	.500	2,634	145	33	48.3
21	4	5,029	.500	2,515	147	2	36.8
22	3	4,343	.500	2,672	140	7	46.7
23	4	3,128	.500	1,564	108	10	27.0
24	5	2,851	.667	2,016	72	14	14.4
25	2	2,732	.500	1,366	55	21	27.5
26	3	2,389	.500	1,195	45	31	15.0
27	4	2,653	.500	1,326	63	4	15.8
28	5	4,065	.500	2,033	140	28	28.0
29	4	4,633	(1)	1,357	162	9	40.5
30	9	5,742	.667	4,060	296	16	32.9
31	5	5,306	.500	2,653	288	25	57.6
32	7	3,168	.667	2,240	143	22	20.4
33	5	2,086	.500	1,043	88	18	17.6
34	5	2,297	.500	1,148	113	12	22.6
35	0	--	--	--	178	--	--
36	0	--	--	--	41	--	--
37	0	--	--	--	110	--	--
					4,071		

[1] Factors for these units have not yet been determined.

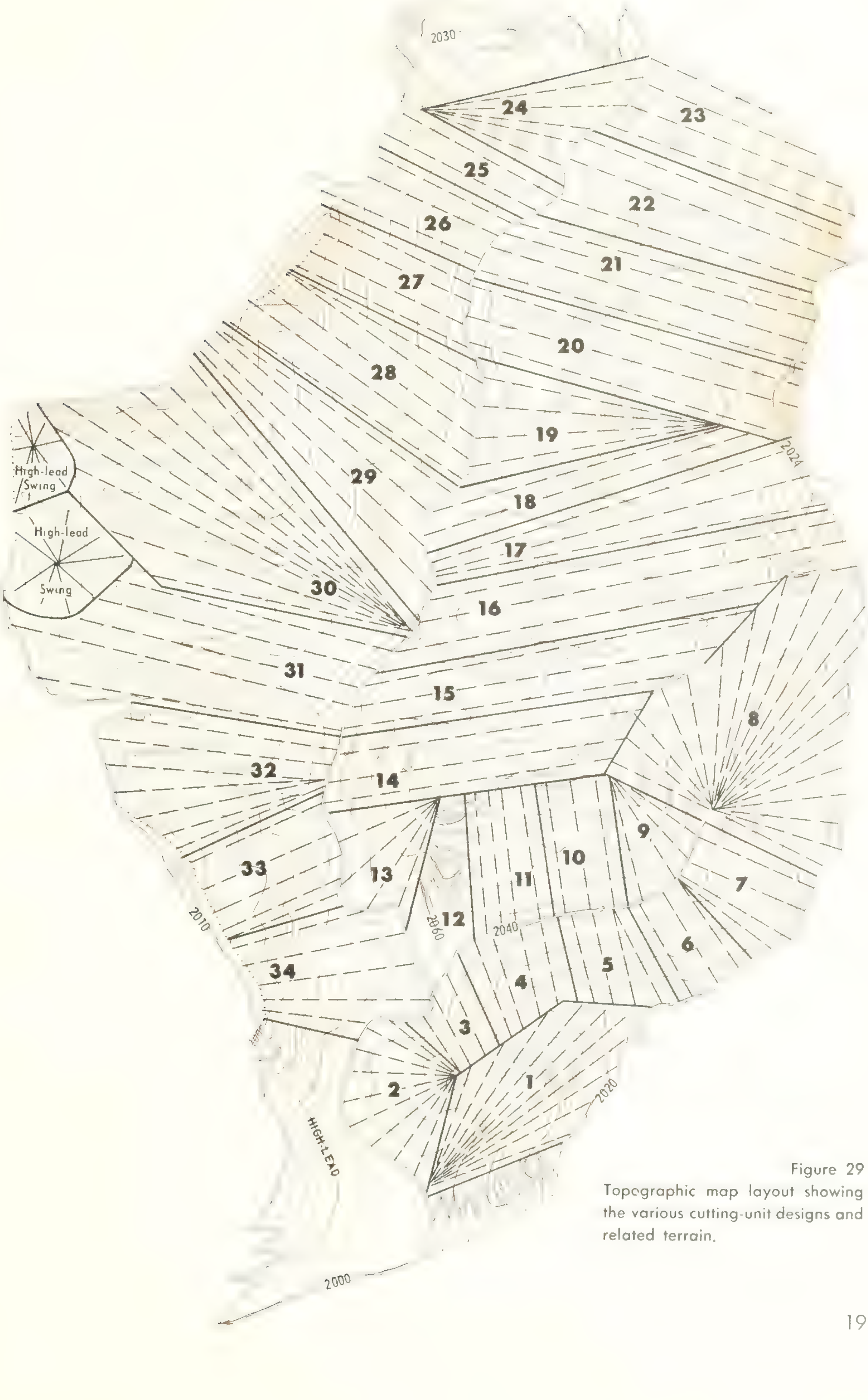

Figure 29
Topographic map layout showing the various cutting-unit designs and related terrain.

Economic Analysis

Two important aspects of new logging systems can be examined by an economic analysis: what phases of the operation are costly yet subject to improvement and what are the total costs under given situations. In this study the economic analysis consisted of a time study of the various phases of the skyline yarding cycle, regression analysis of the major factors affecting yarding time, calculation of hourly labor and equipment costs, and conversion of hourly costs to costs per thousand board feet. These are presented here in detail and an example of cost estimation is included.

Time Study

The time study on the experimental area covered 327 turns, spread over a 6-month period. Timing was generally conducted. in units of whole days or half days so as to obtain an unbiased sample of turn and delay times. Breakdown time was secured from company records; the method of recordkeeping was designed especially for this study.

The six time phases of a logging cycle were timed separately by the snapback technique, recording time to the nearest tenth of a minute. Time for each individual phase was recorded separately. The method of timing is described as follows:

Phase T_1. Time required to move the unloaded carriage from the landing to point of loading. Time started with the signal to start the carriage up the skyline and ended when the carriage reached the point of loading.

Phase T_2. Time required by the rigging crew to pull the skidding line laterally from the carriage to the turn of logs. Time started when the carriage reached the point of loading and ended when the skidding line was pulled laterally to the turn of logs.

Phase T_3. Time required to hook a turn of logs to the carriage skidding line. Time started when the skidding line reached the turn of logs and ended when the rigging crew was in the clear and the signal was given to skid the turn laterally to the carriage.

Phase T_4. Time required to skid turn of logs laterally to the carriage. Time started when the signal was given to skid the turn laterally to the carriage and ended when the turn was under the carriage.

Phase T_5. Time required to move the loaded carriage down the skyline from the point of loading to the landing. Time started with the movement of the carriage and stopped when the carriage reached the landing.

Phase T_6. Time required to unhook a turn of logs. Time started when the carriage reached the landing and ended when the logs were unhooked and the carriage was ready to begin a new cycle.

Analysis of Factors Affecting Time and Cost

Major variables, considered as affecting the various phases of yarding time, were identified and recorded as follows:

D_1 Distance in feet that carriage travels along skyline, measured from skyline profiles using straight-line chords for deflected skyline.

D_2 Lateral slope distance in feet, measured perpendicularly from the skyline.

S_1 Slope of skyline in percent, calculated with horizontal and vertical distances taken from profile, coded in tens in formula, i.e., 80 percent = 8.

S_2 Lateral slope in percent at right angles to the skyline, coded in tens in formula, i.e., 80 percent = 8.

S_3 Ground slope in percent directly under the skyline, coded in tens in formula, i.e., 80 percent = 8.

I Number of intermediate supports.

C	Number of men in rigged crew that pulls skidding line laterally and hooks chokers.
N	Number of logs in each turn.
B	Slash index measured as (1) light, (2) medium, or (3) heavy.
V	Turn volume in board feet, gross scale, Scribner Decimal C. Coded in formula, 1,000 board feet = 100.

Regression equations were calculated for each of the six phases of the yarding cycle based on tests for significance using the following combinations of independent variables:

T_1, carriage haulback time as related to S_1, I, and D.

T_2, time to pull out skidding line laterally from skyline as related to D_2, S_2, B, C, D_2^2, S_2^2, and D_2S_2.[5]

T_3, hooking time as related to S_2, S_3, S_3^2, B, N, and V.

T_4, lateral yarding time as related to D_2, S_2, B, N, V, D_2^2, D_2S_2, and S_2^2.

T_5, time for downhill movement of the loaded carriage as related to I, D_1, S_1, N, V, D_1^2, and ID_1.

T_6, unhooking time as related to N and V.

Only those independent variables were retained whose correlation was statistically significant, measured at the 5-percent confidence level. The surviving equations were as follows, with time measured in minutes (T_1, T_5, T_6), and in tenths of minutes (T_2, T_3, T_4):

	Coefficient of multiple correlation
Carriage haulback time:	
$T_1 = -0.07053 + 0.00819S_1 + 0.10114I + 0.00099D_1$	0.9910
Time to pull skidding line laterally from skyline:	
$\text{Log } T_2 = 0.89995 + 0.0020715D_2$	0.6694
Choker-set time:	
$\text{Log } T_3 = 0.6147 + 0.09082N + 0.03169S_2$	0.5546
Lateral yarding time:	
$T_4 = 3.7056 + 0.00001384D_2V + 0.03839D_2 + 0.004127V$	0.6604
Time for downhill movement of the loaded carriage:	
$T_5 = 1.26906 \quad 0.70866I + 0.000287D_1$	0.9419
Unhooking time:	
$T_6 = 1.37699 + 0.16345N$	0.5822

These equations are shown graphically in figures 30 to 35.

Timing of T_1 and T_5 was done over fixed distances rather than varied distances ranging from zero. The equations were not curvilinear, nor will the curves originate at zero. A total or constant-speed time was developed rather than a curve for acceleration and deceleration of the carriage. Estimated time and distances for these functions are drawn as dashed lines on figures 30 and 34.

The total time in figure 31 is the average total time to lower the skidding line from the carriage and for the rigging crew to untangle chokers before pulling the skidding line laterally to the turn of logs.

Data for three- and four-man rigging crews were recorded and analyzed. The analysis showed, and was verified by referring to the field data, that the four-man crew, working on terrain comparable to that of the three-man crew, consistently required more time. The reason for this time difference could not be identified. Therefore, only the results from the three-man crew will be presented in this paper. Hooking, in comparison of the three- and four-man crews, resulted in the same relationship as in phase T_2. Comparison of crew size for hooking time will also be omitted. Time for hooking with and without present chokers was also compared in this study and, as was expected, preset chokers greatly reduced hooking time. The equation for a three-man crew using preset chokers was selected for presentation in this paper (fig. 32).

Figure 33 is a graphic presentation of phase T_4, the lateral skidding of logs to the carriage. Slope S_2 did not survive as a significant variable in the analysis which led to this presentation.

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[5] Logarithmic transformations were made for T_2 and T_3.

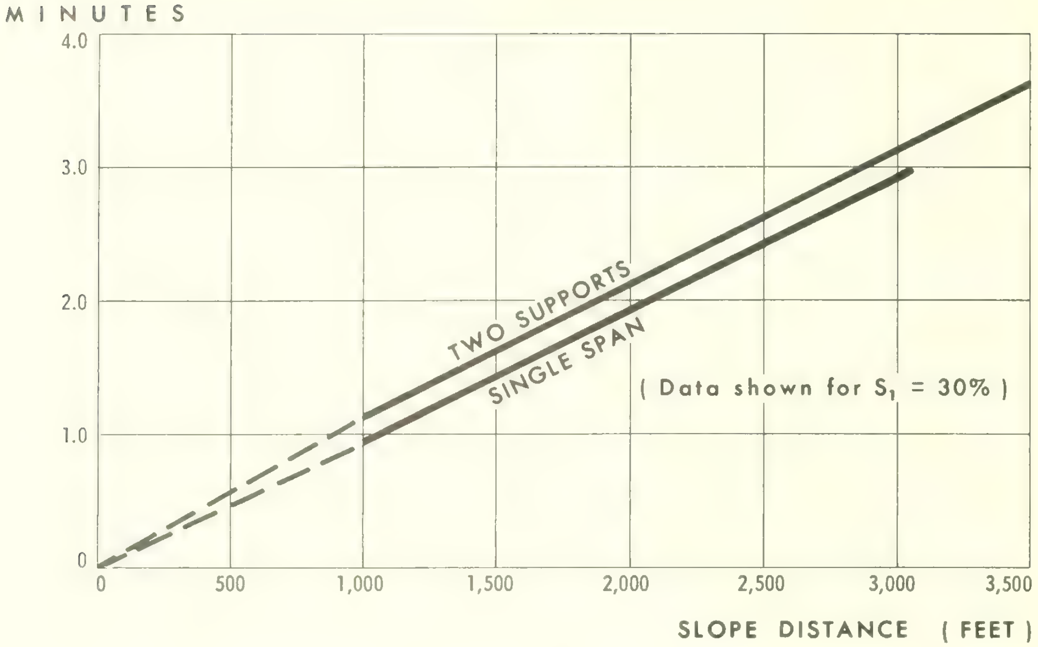


Figure 30.—Carriage haulback time. $T_1 = -0.07053 + 0.00819S_1 + 0.10114I + 0.00099D_1$.

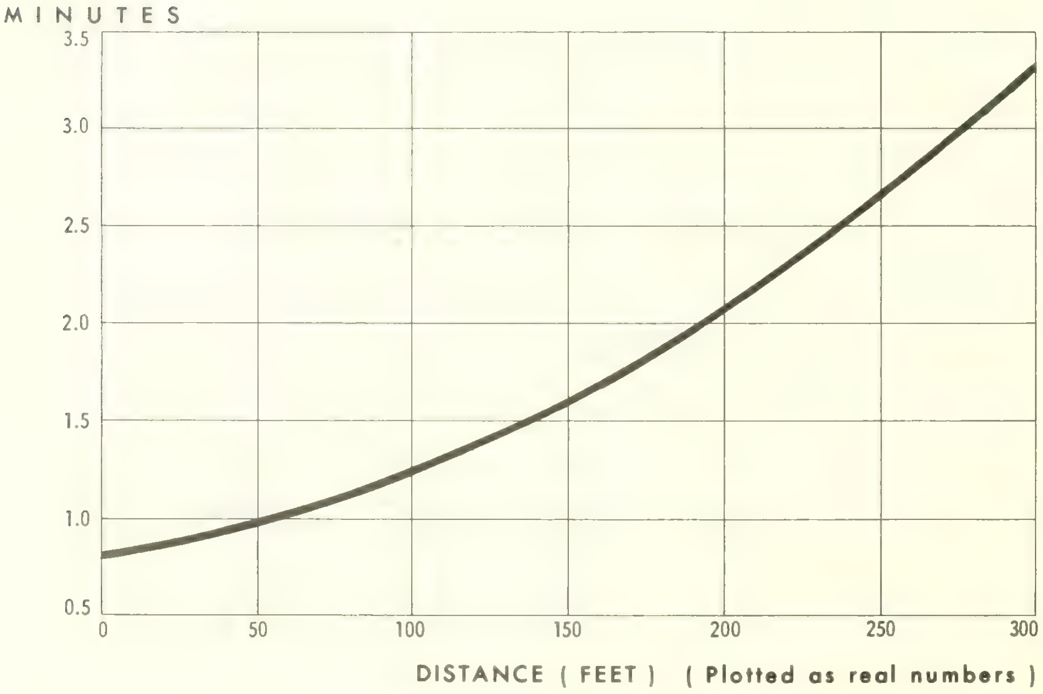


Figure 31.—Time to pull skidding line laterally from skyline (3-man crew). Log T_2 (in tenths of minute) $= 0.89995 + 0.002071D_2$.

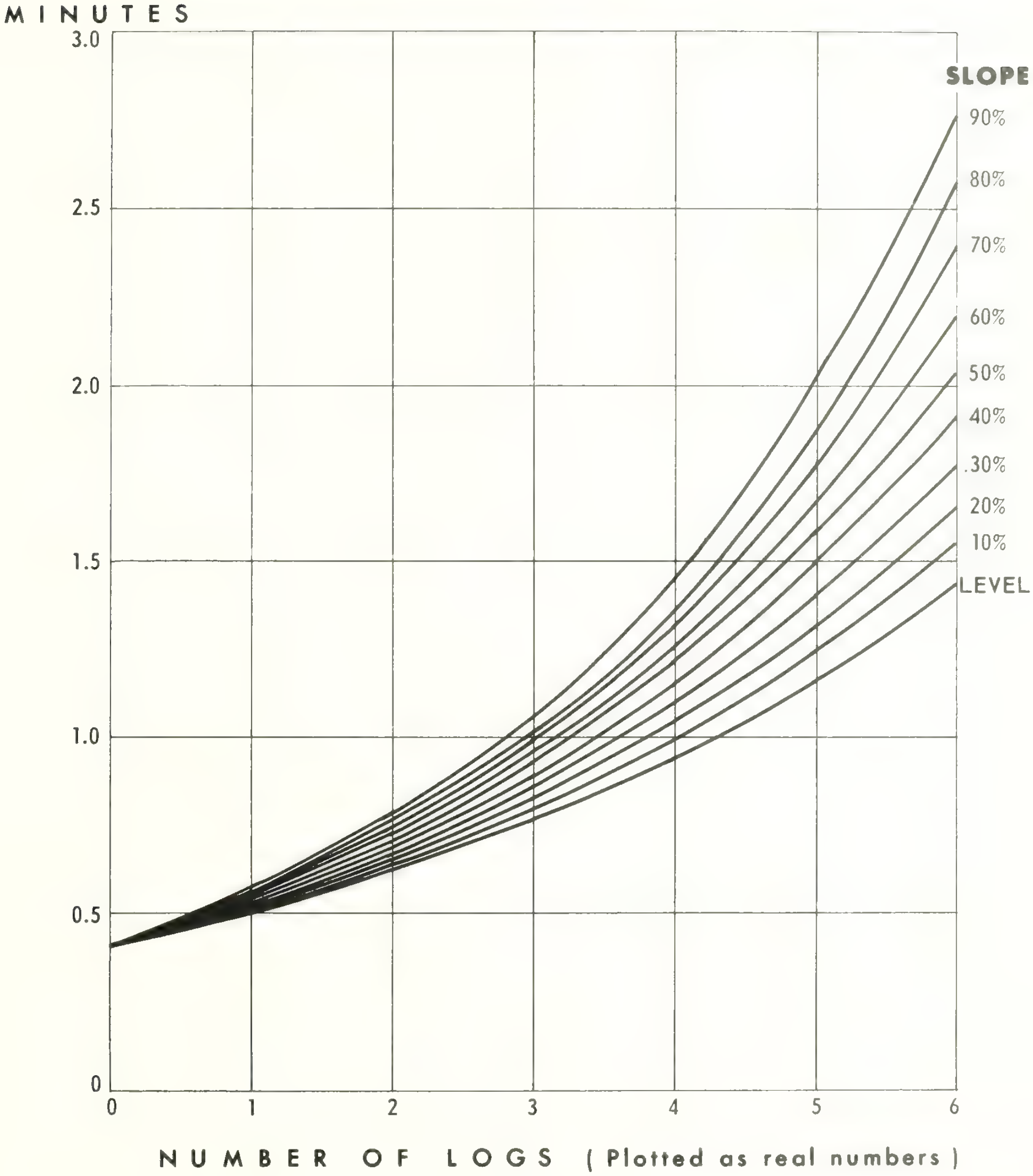


Figure 32.—Hooking time (3-man rigging crew, preset chokers). Log T_3 (in tenths of minute) $= 0.6147 + 0.09082N + 0.03169S_2$.

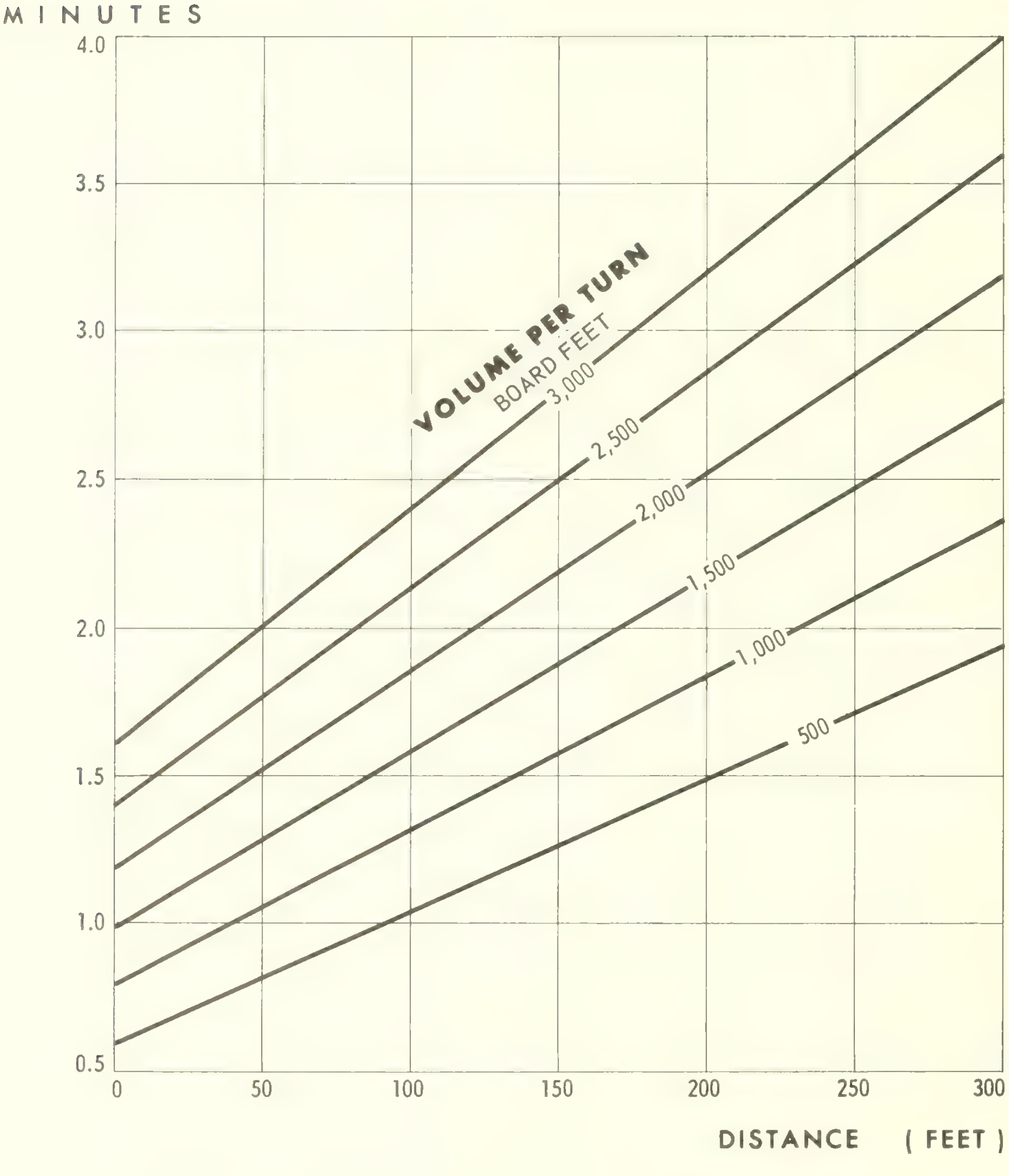
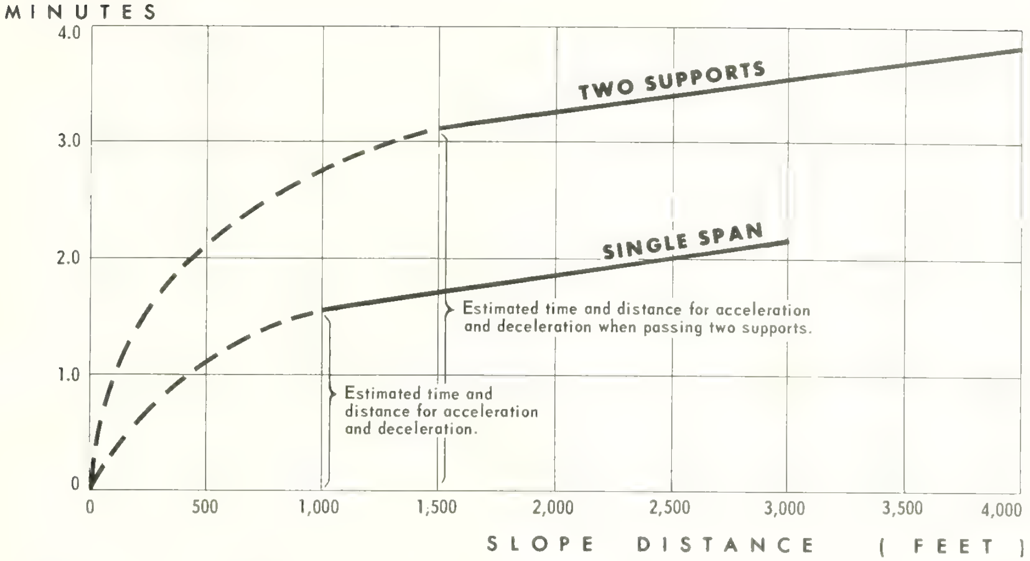


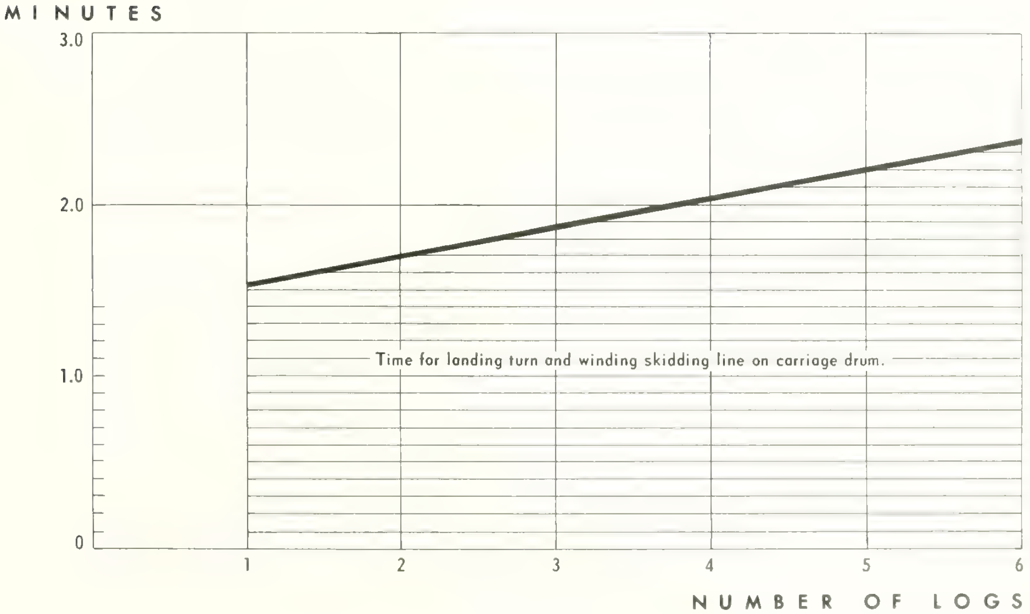
Figure 33.—Lateral yarding time. T_4 (in tenths of minute) = 3.7056 + $0.00001384D_2V$ + $0.03839D_2$ + 0.004127V.



Estimated time and distance for acceleration and deceleration when passing two supports.

Estimated time and distance for acceleration and deceleration.

Figure 34.—Time for downhill movement of the loaded carriage. $T_5 = 1.26906 + 0.70866I + 0.000287D_1$.



Time for landing turn and winding skidding line on carriage drum.

Figure 35.—Unhooking time. $T_6 = 1.37699 + 0.16345N$.

Table 2.—Quantity and cost of equipment for a radio-controlled skyline system

Quantity	Description	Cost
1	Snubbing machine BX185 with hydrotarder[1]	$47,380.00
1	RCC-20 Skycar[1]	23,670.00
1	Radio equipment[1]	5,700.00
		76,750.00
	Rigging equipment:[2]	
1	High-lead block, 24 inches by 3 feet	686.00
2	Tree shoes, 48 inches by 4 inches	1,116.00
1	Multipart heel tackle, 18-inch	1,140.00
1	Skidder head hook, 1-inch	74.25
1	Skidder second hook, 1-inch	77.00
4	Moving blocks, 10 inches by 1-1/2 inches	167.00
4	Rigger's block, 4 inches by 1-1/4 inches	140.00
26	Tree plates, 7 8 inch by 3 inches by 3 feet	702.00
1	Claw bar, 3-foot	27.00
1	Rigger's pass chain, 3/8 inch by 7-1/2 feet	28.00
1	Rigger maul	21.00
1	Splicing needle, 12-inch	7.50
2	Splicing needles, 18-inch	16.80
1	Splicing needle, 20-inch	10.00
1	Rigger's belt with rope and chain[3]	47.90
1	Set climbing spurs[3]	29.50
12	Wire rope clips, 2-inch	306.00
34	Guy line sleeves, 1-1/4 inch	459.00
4	Winch line clevises, 1-3/8-inch	86.40
4	Tree straps,[3] 2 inches by 18 feet	759.36
2	Tree straps,[3] 2 inches by 16 feet	367.96
2	Tree straps,[3] 2 inches by 12 feet	344.52
16	Guy lines, 3/4 inch by 200 feet[1]	1,216.00
16	Guy lines, 1 inch by 200 feet[4]	1,856.00
300 lbs.	Railroad spikes	36.00
	Miscellaneous tools[5]	500.00
1	Portable guy line tightener[6]	38.50
1	Operating line roller[5]	600.00
1	Chain saw[3]	297.35
		11,157.04
	Wire Rope:[4]	
1	Skyline, 2 inches by 5,000 feet	10,650.00
1	Snubbing line, 1 inch by 5,000 feet	2,900.00
1	Straw line, 3/8 inch by 6,000 feet	960.00
2	Carriage load lines, 3/4 inch by 500 feet	380.00
25	Chokers, 5/8 inch by 20 feet[2]/[5]	217.00
		15,107.00
	Fire equipment:[6]	
4	Water barrels[5]	20.00
6	Shovels	24.00
6	Fire axes	68.28
4	Backpack pumps	96.00
	Fire hose, 1 inch by 1,000 feet	500.00
1	300 gal. portable pump[5]	1,500.00
1	500 gal. firetruck and pump[5]	2,500.00
		4,708.28
	Engineering supplies:[6]	
1	Staff compass	60.50
1	Jacob's staff	6.00
1	200-foot engineer's chain	45.40
1	Machete	2.95
2	Abney levels	72.00
	Miscellaneous engineering supplies	50 00
		236.85
	Total	$107,959.17

[1] Skagit Steel & Iron Works.

[2] Young Iron Work catalog.

[3] Local retailer.

[4] Broderick and Bascom catalog.

[5] Estimate.

[6] Retail catalog.

Calculation of Hourly Costs

LABOR COSTS.—The five-man crew includes engineer (snubbing-machine operator), rigging slinger (man in charge of rigging crew), two choker setters, and chaser (unhooker at landing). Wages, plus payroll overhead of approximately 22 percent for social security, vacation pay, accident insurance, and related charges, were estimated at $150 per day, or $18.75 per hour.

EQUIPMENT COSTS.—Costs of equipment were calculated as shown in tables 2, 3, and 4. Average investment was calculated as one-half the sum of original cost and salvage value. Basis of calculation was 215 operating days per year. Interest was calculated at 6 percent, and was considered an economic cost, whether or not interest payments are made, because if internal funds are used to purchase equipment, they cannot earn an approximately equivalent rate elsewhere. Taxes were calculated at 2 percent of average investment. Insurance was calculated at $1.25 per $100 for 80 percent of average investment. Lubrication cost of machines was calculated at 15 percent of fuel cost. Repairs and maintenance were calculated at 50 percent of depreciation for the snubbing machine, or 90 percent for Skycar and radio equipment.

EFFECT OF DELAYS AND BREAKDOWN TIME.—A record was kept of total operating and nonoperating hours for the period the skyline equipment was on the study setting. There were 1,357 operating hours and 215 nonoperating hours, for a total of 1,572 hours. Operating hours were therefore 86.3 percent of total time available for productive yarding.

Table 3.—Derivation of average investment and fuel cost and consumption for yarding equipment

Item	Useful life	Original cost	Salvage value	Average investment	Fuel cost, per gallon	Fuel consumption, per hour
	Years	Dollars				Gallons
Snubbing machine	7	47,380	9,476	28,428	0.165	8
Skycar carriage	7	23,670	2,367	13,019	0.195	2
Radio equipment	7	5,700	0	2,850	--	--
Rigging equipment	3	11,157	1,116	6,136	--	
Wire rope	3	14,510	1,451	7,981	--	--
Fire equipment	5	4,708	471	2,589	--	--
Engineering equipment	5	474	--	--	--	--

Table 4.—Calculation of hourly costs for yarding equipment (In dollars)

Item	Costs per day									Total cost, per hour
	Depreciation	Interest	Taxes	Insurance	Fuel	Lubrication	Repairs and maintenance	Other	Total	
Snubbing machine	25.19	7.93	2.64	1.32	10.56	1.58	12.60	--	61.82	7.73
Skycar carriage	14.15	3.63	1.21	.61	2.64	.40	12.74	--	35.38	4.42
Radio equipment	3.79	.80	.27	.13	--	--	3.41	--	8.40	1.05
Rigging equipment	15.57	1.71	.57	--	--		--	--	17.85	2.23
Wire rope	20.25	2.23	.74	--	--	--	--	[1]2.78	26.00	3.25
Fire equipment	3.94	.72	.24	--	--	--			4.90	.61
Engineering equipment	.22	--	--	--	--	--	--		.22	.03
Total										19.32

[1] Covers 25 chokers per year ($217) plus two skidding lines per year ($380).

Direct Costs Per Thousand Board Feet

The regression equations for time were used to calculate times per turn. These times, multiplied by labor and equipment costs per minute, will give direct cost per turn; such costs, divided by turn volume, give direct cost per thousand board feet (fig. 36).

These direct costs show only the extra cost of yarding an extra turn; they do not include development costs, rigging costs, and costs of felling and bucking, crew transportation, supervision, or general overhead.

Note that the calculated direct yarding costs can vary from over $25 per thousand board feet for a turn volume of 250 board feet to about $3 per thousand board feet for a turn volume of 2,500 board feet for a given span distance. This illustrates the importance of turn volume as a cost-determining factor.

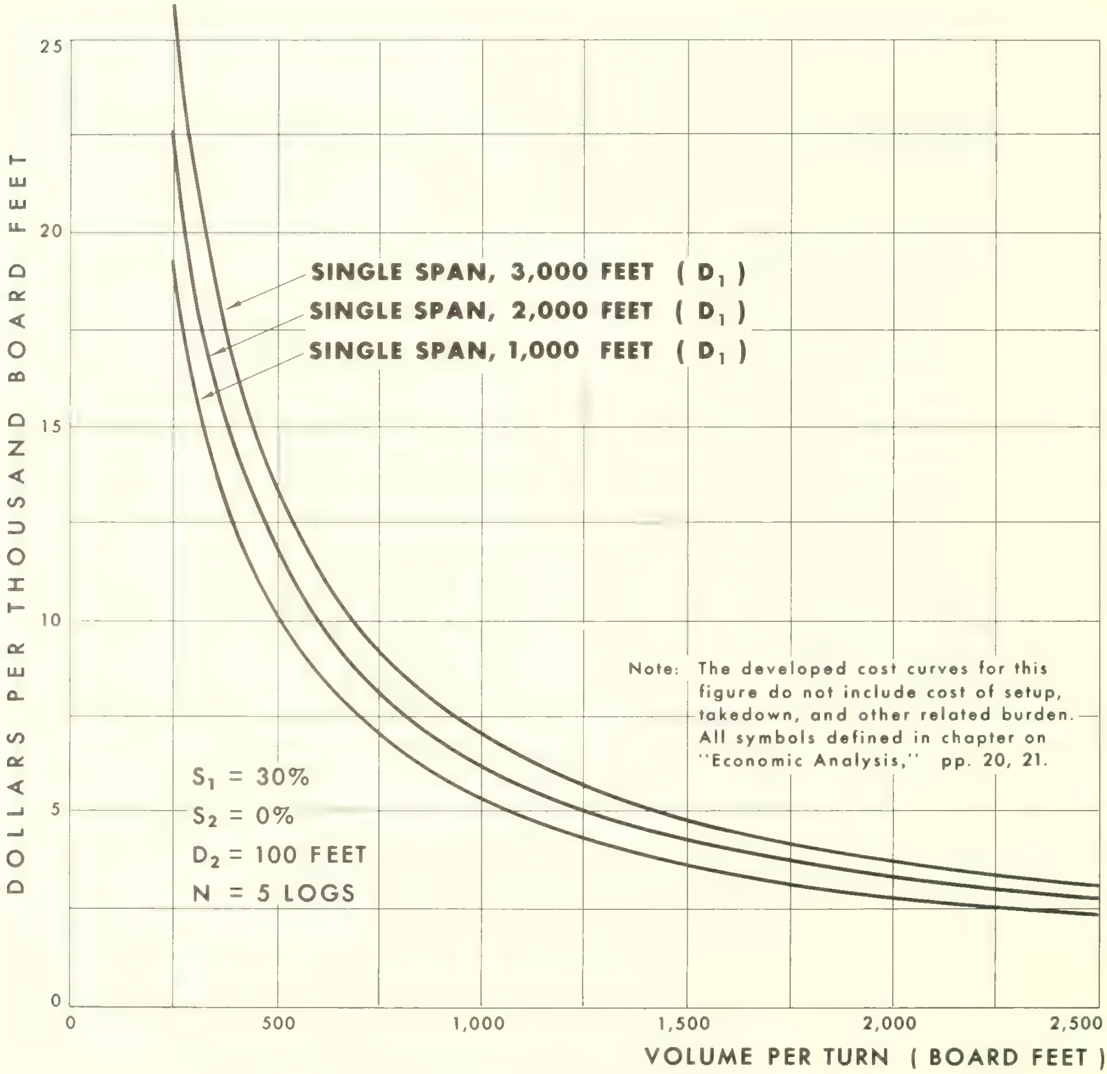


Figure 36.—Direct yarding cost per thousand board feet as related to carriage loading.

Application of Results

The foregoing information on layout, design, and cost estimating can be used for planning possible skyline operations over a wide range of operating conditions. Calculation of average times for the six individual phases of the yarding cycle will permit estimation of production rates and average yarding costs. Timber sale administrators and logging managers will find that such planning is not difficult and that it leads to a clearer understanding of the operating requirements for efficient use of skyline methods and equipment.

A Practical Example

A practical example is developed below, using data obtained in this study. In developing this example, the following conditions are assumed:

1. Rectangular setting, 800 by 2,500 feet horizontal distance
2. Single-span skyline
3. Gradient of skyline, 30 percent
4. Lateral slope, zero percent under the skyline
5. Spar support, needed at top and bottom.
6. Volume per acre, 45,000 board feet, gross scale
7. Scaling defect, 13 percent
8. Average log, 300 board feet, gross scale
9. Average load, five logs, or 1,500 board feet
10. Operating crew, five men
11. Use of preset chokers
12. Effective work hour, 50 minutes
13. Average lateral yarding distance, 100 feet
14. Average skyline distance, 1,300 feet (obtained graphically)

Estimated times are as follows:

Average T_1 = 1.25 minutes
Average T_2 = 1.22 minutes
Average T_3 = 1.16 minutes
Average T_4 = 1.58 minutes
Average T_5 = 1.61 minutes
Average T_6 = 2.20 minutes
Total 9.02 minutes

With an estimated 50-minute effective work hour, 9.02 minutes per turn will result in 5.54 turns per clock hour. Then, 5.54 turns per hour multiplied by 1,500 board feet per turn multiplied by 8 hours per day = 66,480 board feet per day, gross scale, and 66,480 multiplied by 0.87 = 57,838 board feet per day, net scale.[6]

Yarding Costs

Estimated yarding costs are as follows:

		Average cost per thousand board feet, net scale (Dollars)
Labor cost:		
$150 per day / 57,838 board feet per day		2.59
Rigging cost:		
4 spar trees at $1,000 per tree	$4,000	
4 tail holds at $500 each	2,000	
Move-in and miscellaneous rigging, 5 days, including labor and machine cost	1,100	
	$7,100	
45.91 acres x 45,000 board feet per acre x 0.87 = 1,797,000 board feet, net scale		
$7,100 divided by 1,797		3.95
Machine cost:		
$19.32 x 8 hours per day / 57,838 board feet per day		2.67
Total		9.21

Discussion

A critical assumption in the above example is that turn volumes will average 1,500 board feet.

It was observed that unhooking, which accounts for 21 percent of the cycle time in the example, could be reduced by releasing the chokers from the butt-hooks and attaching a new set of empty chokers to be sent back with the empty carriage. The chokers could be unhooked while the logs are being moved from the landing area to the various sorting piles. Reducing cycle time by 1 minute in the example would increase production 7,203 board feet, net scale, per day.

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[6] The figure 0.87 accounts for 13 percent scaling defect.

Use of average times, production rates, and costs provides a useful method of analysis. However, this does not eliminate the need for attention to the wide variation in times and costs for individual turns. Uneconomic individual turns and logs should be avoided wherever possible by close supervision following careful planning. The relatively high, fixed costs of this equipment make its minimum economic load much greater than for other yarding methods.

Concluding Remarks

Skyline yarding systems offer an effective means of moving logs from steep slopes where special precautions must be taken to minimize soil disturbance. This is an important objective where there is relatively thin, unstable soil or terrain unfavorable for road construction.

For efficient performance, skyline yarding systems must be carefully planned, engineered, and supervised. This is necessary, not only from the standpoint of technical efficiency but also to keep down the relatively high costs of rigging, to avoid delays, and to achieve production rates that justify the relatively high, per-hour operating costs.

Multispan skylines tend to cost more than single-span skylines. This is reflected in increased cycle time, extended periods of nonproduction while rigging and dismantling the intermediate supports, and by the cost of this rigging. External distances up to 3,000 feet can be attained with a single span on certain topographic features; however, distances of not over 2,000 feet are more desirable. Introduction of the skyline-crane yarding system into a forest harvest plan should be done with a single-span setup until operators and logging crews become familiar with the system. Skyline profiles should be made and cutting-unit layout planned prior to moving equipment to the site.

During the course of this study, several possibilities were noted for reducing costs. These include use of preset chokers to reduce cycle time, changing gear ratios on the yarder to increase speed of the empty carriage up the skyline, improvement of the tote road to the top of cutting unit to permit use by 4-wheel drive or track-type personnel carriers, and development of a safe device to permit personnel to ride the carriage.

Carriage loading is a significant factor in attaining the designed production of the skyline system. Study of the various time elements will show that loading the carriage to designed capacity causes a slight reduction in number of turns per hour but results in a greatly increased hourly and daily volume production.

Although direct yarding costs for skyline yarding are generally greater than for conventional high-lead yarding, these are offset in part by the reductions in road costs, truck hauling distance, and log breakage. Therefore, a complete cost analysis is needed before a choice is made among alternative logging systems. This report provides information and procedures for such analysis of skyline logging.

GPO 988-376

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Seasonal Progress of
RADIAL GROWTH of Douglas-fir Western Redcedar and Red Alder

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INTRODUCTION

To determine the duration of the growing season and the distribution of growth over the season, measurements of radial growth were made for 5 years at McCleary Experimental Forest, in western Washington.[1]

Information provided by this study should be of interest, not only to those concerned with measuring short-term responses to treatment or environment but also to those concerned with remeasuring trees on permanent sample plots. Results clearly show progress of growth over the season to be extremely variable from one year to another. This makes it difficult to assess the proportion of total growth completed by a given date and indicates the importance of avoiding the growing season, if at all possible, when periodic measurements are made on permanent sample plots

The literature contains many reports of similar measurements on a wide number of the tree species (Bannan 1962; Bormann and Kozlowski 1962).[2] In many cases, measurements have been more frequent and under better controlled conditions, but usually they have covered only a 1- or 2-year period Also few such measurements have been made on the species herein reported. Dimock (1964) reported observations on younger Douglas-fir in the same vicinity as this study, and Warrack and Joergensen (1950) reported on measurements to evaluate the effect of thinning on growth of Douglas-fir in British Columbia.

THE STUDY

Measurements were made on four groups of 10 trees each--two of Douglas-fir and one each of western redcedar and red alder. One group of Douglas-fir trees (group 1) was near the top of a hill on west-to-southwest aspect, at an elevation of about 575 feet; the other (group 2) was on a moderate, westerly facing sidehill at an elevation of about 370 feet. Cedar trees were on a flat at an elevation of about 375 feet, and alders were on a flat at an elevation of about 330 feet. Douglas-fir trees were about 65 years old in 1954; cedar and alder were about 50 years old.

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[1] McCleary Experimental Forest is maintained by the Pacific Northwest Forest and Range Experiment Station in cooperation with Simpson Timber Co. The study was begun by George R. Staebler in 1954 and continued by Edward J Dimock II.

[2] Names and dates in parentheses refer to Literature Cited, p. 14.

Trees were chosen to minimize variations in crown class and diameter. Most were strong codominants. Starting diameters and 5-year radial growth are summarized in table 1.

Table 1.--1954 d.b.h. and subsequent 5-year radial growth (north side) of study trees

Tree number	Douglas-fir, group 1		Douglas-fir, group 2		Western redcedar		Red alder	
	D.b.h.	Growth	D.b.h.	Growth	D.b.h.	Growth	D.b.h.	Growth
	Inches							
1	15.6	0.312	15.9	0.423	10.3	0.715	10.4	0.218
2	17.1	.255	22.7	.567	10.5	.284	10.9	.256
3	15.7	.383	17.3	.406	11.6	.205	10.3	.393
4	16.6	.328	17.5	.107	10.9	.442	12.7	.287
5	18.9	.372	20.8	.372	8.4	.292	11.0	.234
6	15.9	.427	19.8	.208	10.5	.428	9.4	.311
7	16.4	.804	21.2	.721	10.6	.218	9.1	.101
8	15.3	.414	20.9	.897	9.5	.393	8.5	.212
9	15.4	.432	18.2	.320	9.3	.303	9.4	.161
10	17.5	.283	20.4	.483	10.0	.345	8.4	.110
Average	16.4	.401	19.5	.451	10.2	.362	10.0	.229

Measurements were made in thousandths of an inch with a dial gage dendrometer. Roundhead brass screws, driven into the wood of the trees, were used for bearing points, and 3/8-inch squares of copper or aluminum, stuck to a smoothed portion of the bark with fast-drying model airplane cement, were used for contact points. The screws formed the corners of a right triangle, so that no screw was directly below the point where growth was measured.

Changes in radius were recorded cumulatively from the first measurement in April 1954 to the final measurement in November 1958. During each growing season, measurements were made weekly until it was established that true growth had been underway for at least 2 weeks, and then every 2 weeks until growth apparently stopped. In group 1, radius changes were recorded on four sides of the trees--north, east, south, and west. In all other groups, measurements were made only on the north side of trees.

RESULTS AND DISCUSSION

Changes in radius due to moisture and the adequacy of measuring trees on only one side are discussed first to provide a background for interpreting progress of seasonal growth. Variations in precipitation and temperature are also presented to show their relationship to year-to-year differences in pattern of radial growth.

Changes in Radius Due to Moisture

Shrinking and swelling of tree trunks due to moisture changes masks actual growth in many instances, and the reader should be aware that reported changes in radius are the sum of true growth and this shrinking or swelling (Kozlowski 1962).

Data collected during the early part of the 1956 growing season from a setup on a recently dead tree showed the considerable impact that moisture changes can have. The most drastic changes were shrinkage of 0.01 inch during the period April 6-20 and swelling of the same amount during the period June 1-15; a hundredth inch is about 15 percent of average annual growth on nearby living codominant trees. The dead tree did not provide a completely valid measure of shrinking and swelling due to moisture changes in live trees, but it was indicative of the effect moisture alone can have.

Substantial changes in radius between the last measurement in the fall and first measurement the following spring are due in part to swelling and shrinking. During the winters of 1954-55, 1955-56, and 1957-58, most trees showed some increase in radius, the increase generally being greater on Douglas-fir than on cedar and alder. Between the 1956 and 1957 measurements, however, the north radius of most trees shrank substantially--8.5 percent of the 1956 seasonal growth for Douglas-fir, 18.5 percent for cedar, and 30.0 percent for alder. Over the other three winters, increase in radius of Douglas-fir averaged 6.9 percent of the seasonal growth; cedar, 3.2 percent; and alder, 4.6 percent.

Tree trunks also undergo small amounts of diurnal shrinking and swelling. which could have some effect on changes from one measurement to another (Kozlowski 1962). However, most measurements were made in late morning, so this factor had negligible influence except as reflected in the seasonal variation.

Adequacy of One Measurement Per Tree

On the 10 Douglas-fir trees where radial changes were measured on four sides amount of annual growth differed substantially and significantly between sides, as well as between years (table 2). Growth averaged 42 percent greater on the east side than on the south side

Table 2.--Average seasonal radial growth of Douglas-fir, by side of tree and year (basis: 10 trees)

Year	North side	East side	South side	West side
	Inches			
1954	0.089	0.087	0.057	0.074
1955	.102	.110	.081	.093
1956	.057	.062	.043	.050
1957	.072	.082	.058	.061
1958	.076	.077	.058	.056
Average	.079	.084	.059	.067

This relationship between growth rate and cardinal direction may indicate a buildup in windfirmness in response to southwesterly winds (Ruth and Yoder 1953), or it may otherwise be associated with the near ridgetop position of these trees. Other factors--perhaps relative competition on various sides of the tree, slope, root grafts, etc.--sometimes overshadowed this trend.

Despite differences in amount of growth, progress of growth during the season was very similar for all sides (table 3). The

Table 3.--Variation between sides of Douglas-fir trees in progress of seasonal radial growth (basis: 10 trees)

Year	Date	Percent of radial growth completed			
		North side	East side	South side	West side
1954	Apr. 25	-5	-6	-9	-7
	May 25	11	10	3	8
	June 24	40	41	39	39
	July 24	65	67	66	64
	Aug. 23	88	90	91	90
	Sept.22	99	99	97	99
1955	Apr. 25	10	8	10	7
	May 25	20	19	21	19
	June 24	48	49	53	51
	July 24	74	75	79	77
	Aug. 23	93	94	95	94
	Sept.22	97	98	98	98
1956	Apr. 25	-5	-6	-13	-11
	May 25	25	22	16	22
	June 24	51	45	43	46
	July 24	78	71	65	71
	Aug. 23	93	90	86	88
	Sept.22	93	91	87	89
1957	Apr. 25	5	4	4	4
	May 25	38	37	38	42
	June 24	64	63	64	69
	July 24	81	79	81	85
	Aug. 23	94	93	94	96
	Sept.22	92	91	88	91
1958	Apr. 25	5	5	5	5
	May 25	45	43	44	47
	June 24	77	74	80	81
	July 24	74	73	72	72
	Aug. 23	83	82	78	80
	Sept.22	91	90	87	87

average maximum deviation between sides, in percent of growth completed by any given date, was less than 5 percent; the greatest deviation was 13 percent. In 1956, relative growth consistently progressed more rapidly than average on the north side and less rapidly on the south side. In 1957, relative growth progressed slightly more rapidly on the west side. However, even these differences were fairly minor, and in other years there were no consistent differences between sides.

Many minor differences between sides appear to be due partly to shrinking and swelling. Apparent changes due to moisture were generally of about the same magnitude on all sides. Therefore, when these changes are expressed as percent of total seasonal growth, they are relatively greater on sides making less than average growth.

Measurement on only one side of the stem is apparently sufficient for determining progress of radial growth throughout the season, although not for determining amount of growth.

Beginning and End of Growing Season

The time that growth begins in the spring and ends in the fall can only be approximated, because of the masking effect of shrinking and swelling. Generally, most of the true growth of all species apparently took place between mid-April and early September. However, there was considerable year-to-year variation (figs. 1-5).

For Douglas-fir, distinct turning points in the growth curves marked the apparent start of growth about May 10 in 1954 and April 20 in 1956 and 1957. In 1955 and 1958, growth apparently started in early April. Growth of cedar and alder apparently started about 3 weeks earlier than Douglas-fir in 1954; growth of alder started about a month later than Douglas-fir in 1958.

The period of rapid growth of Douglas-fir ended about September 15 in 1954; August 15 in 1955, 1956, and 1957; and June 25 in 1958. However, only in 1954 was growth completed by the date indicated. In 1955, a slow increase in radius continued to the last measurement in mid-October. In other years, there were irregular changes in radius, with some growth apparently taking place into October and, perhaps, November. Corresponding dates for other species differed only slightly.

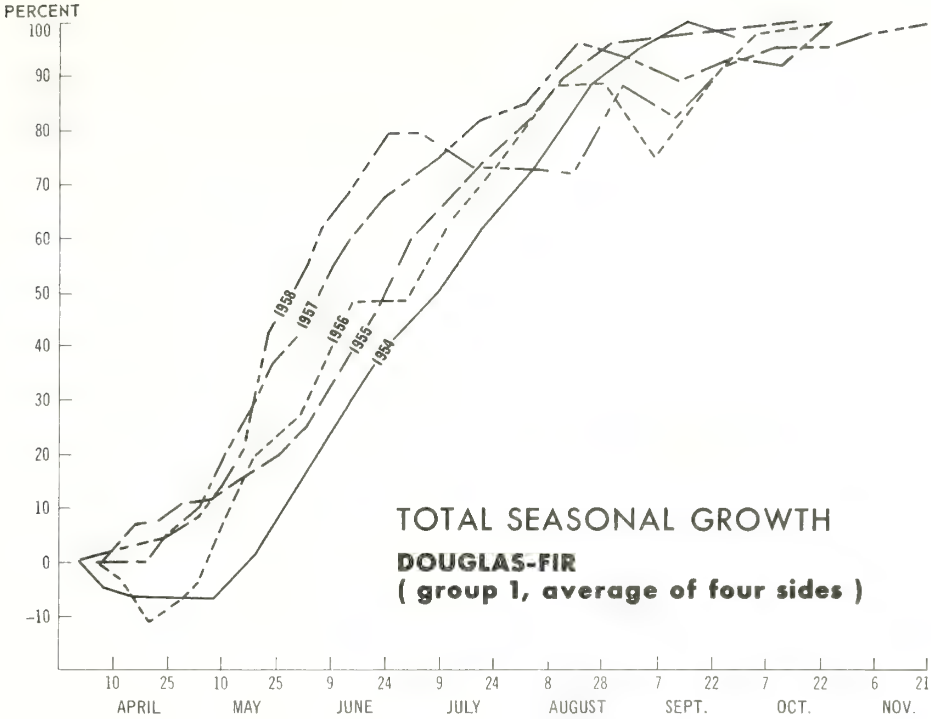

Figure 1.--Seasonal distribution of radial growth on Douglas-fir (group 1, average of four sides), 1954-58.

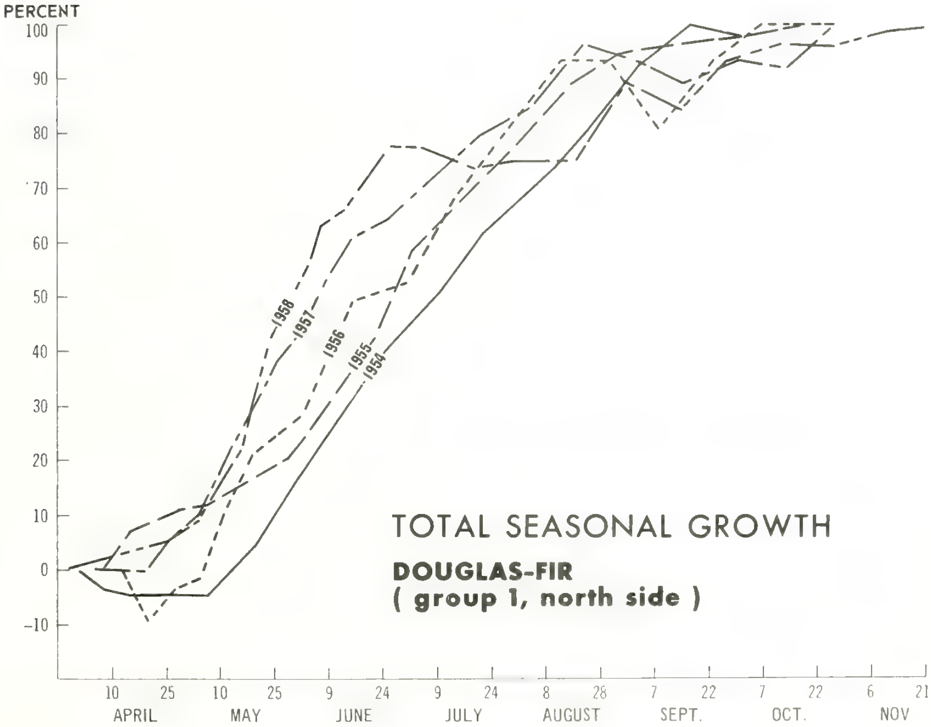

Figure 2.--Seasonal distribution of radial growth on Douglas-fir (group 1, north side), 1954-58.

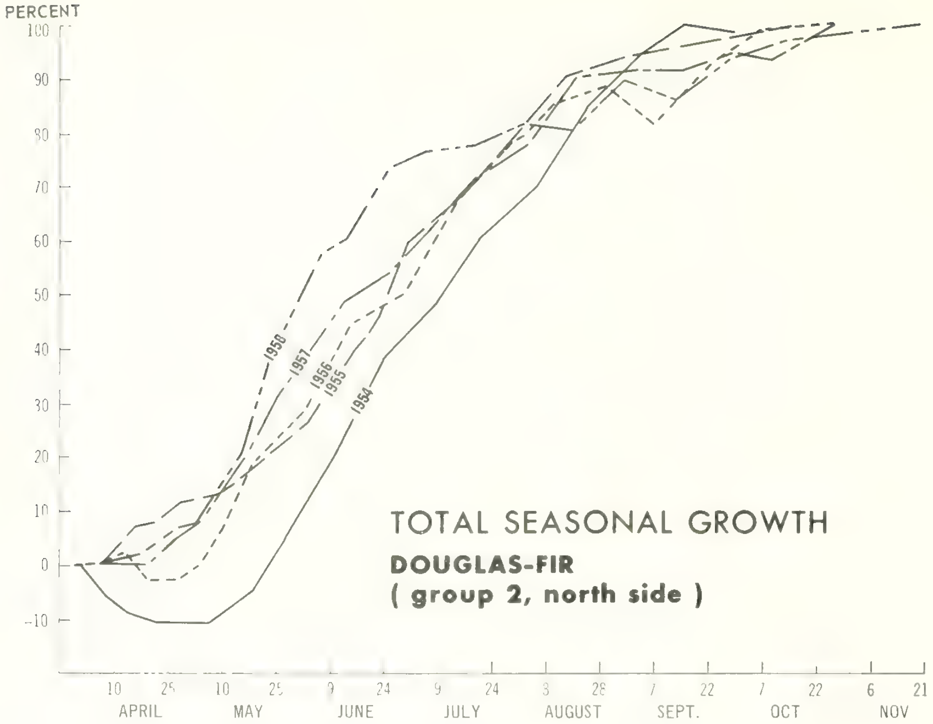

Figure 3.--Seasonal distribution of radial growth on Douglas-fir (group 2, north side), 1954-58.

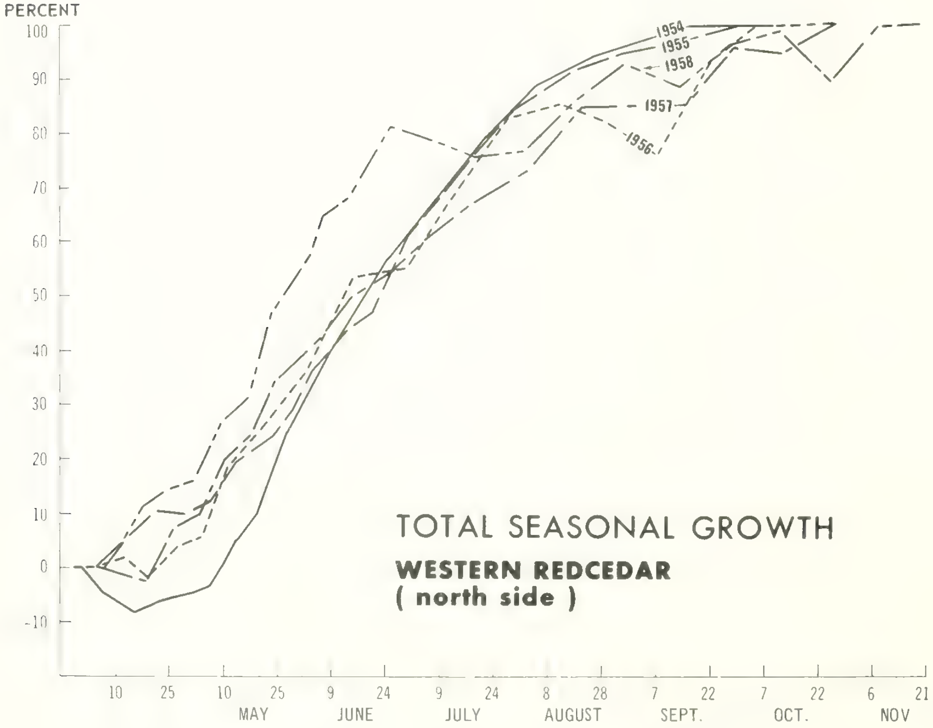

Figure 4.--Seasonal distribution of radial growth on western redcedar (north side), 1954-58.

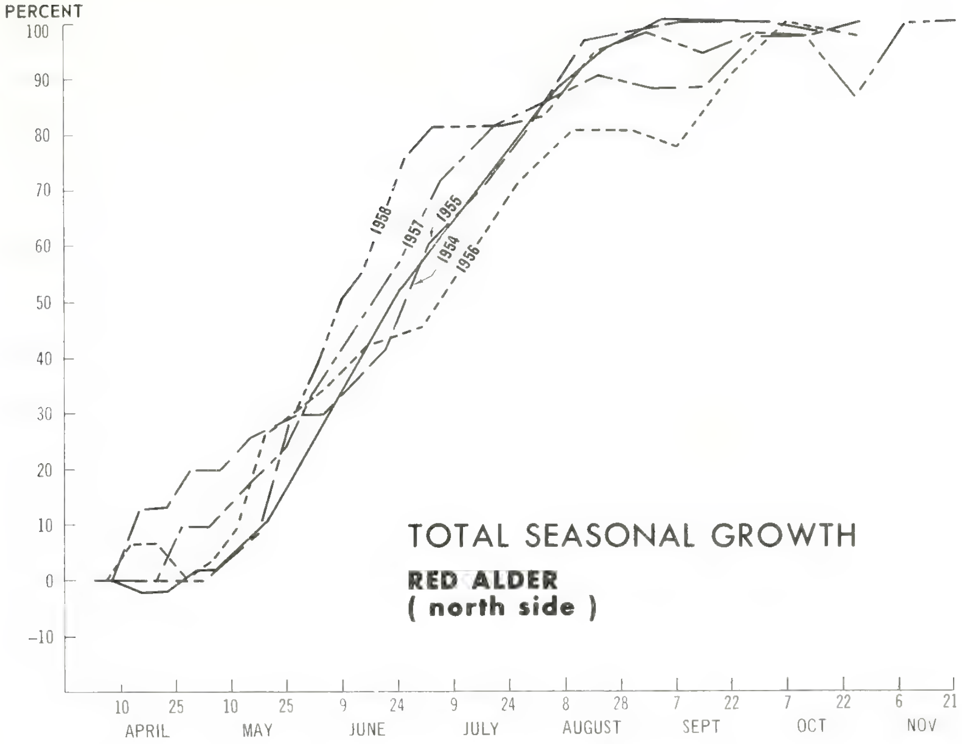

Figure 5.--Seasonal distribution of radial growth on red alder (north side), 1954-58.

Distribution of Growth Over the Season

The distribution of growth over the season is perhaps most easily visualized when growth to any given date is expressed as a percent of the total seasonal growth (figs. 1-5). For illustrative purposes, the growing season has been taken as the period from the first measurement to the highest reading. The trend lines show actual growth plus or minus changes due to shrinking and swelling. Since there was some growth between measured periods, the indicated percent of total growth completed by a given date would differ somewhat if measurements had been taken over a longer or shorter period, but the impact on the total curve would not be appreciable.

Relative growth distribution for each year is summarized in table 4 for Douglas-fir in group 1 (average of four sides) to further illustrate differences between years. On the average of the 5 years, growth was 27 percent complete by May 25. However, this varied from 8 percent in 1954 to 45 percent in 1958. Similarly, growth completed by June 25 averaged 57 percent but varied from 40 to 79 percent.

Table 4.--Seasonal distribution of growth for Douglas-fir, group 1 (average of four sides), by years

Date	1954	1955	1956	1957	1958	Average
	Percent of total seasonal growth					
Apr. 25	-7	9	-9	5	5	1
May 25	8	20	23	38	45	27
June 24	40	50	48	67	79	57
July 24	64	76	73	82	73	74
Aug. 23	90	95	89	95	81	90
Sept. 22	99	98	89	92	90	94
Oct. 22	--	--	100	100	96	99
Nov. 21	--	--	--	--	100	100

Even during the generally most active part of the growing season, shrinkage sometimes offset or exceeded growth. The most notable example was during the period June 24 through August 15, 1958. On Douglas-fir (group 1), "growth" was 79 percent completed by June 24 in 1958, compared with the average for this date of 57 percent. But on August 15, it was only 72 percent completed, compared with the average for that date of about 88 percent (fig. 1). In 3 of 5 years, there were shrinkages in mid-September. Actual growth is probably nearly completed by this time, but weather-caused fluctuations still have substantial impact.

The relative seasonal distribution of growth of the three species likewise varied from one year to another. In 1955 and 1957, distribution of growth was nearly the same for all species. In 1954, growth of both cedar and alder was more advanced than that of Douglas-fir throughout the season, whereas in 1956 that of Douglas-fir was more advanced during parts of the season. In 1958, cedar grew similarly to Douglas-fir; alder started slowly and then went ahead. Both cedar and alder shrank substantially in October, but Douglas-fir continued to increase in radius.

Growth and Weather

Variations in amount and seasonal distribution of precipitation (fig. 6) undoubtedly caused many of the variations in growth patterns. For example, decreases in radius in April 1956 and July 1958 were associated with exceptionally low rainfall. On the other hand, delayed growth in 1954 and rapid growth in May of 1957 and 1958 showed no apparent relationship to precipitation. The latter two may be a reflection of comparatively warm April-May temperatures (table 5). That such relationships cannot be seen for all variations is probably because the combined effect of precipitation, temperature, and wind cannot be properly assessed from available data.

Differences in total growth in 1954 and 1955 are difficult to explain since weather was very similar in the 2 years. The poor growth in 1956 and erratic growth thereafter can be attributed, in

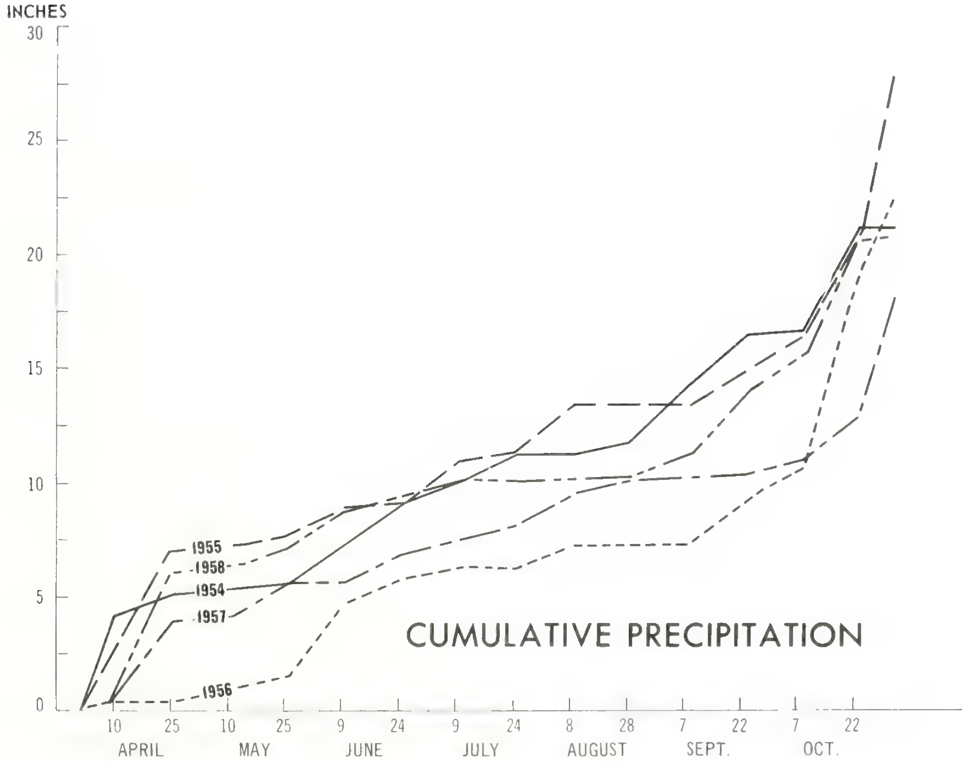

Figure 6.--Cumulative distribution of precipitation, 1954-58, Elma, Wash.

Table 5.--Average monthly temperature, Elma, Wash.[1]

Month	Year				
	1954	1955	1956	1957	1958
	Degrees F.				
April	46.6	45.0	52.3	50.7	50.7
May	53.8	51.9	57.9	57.5	60.8
June	(2/)	58.9	56.8	60.4	65.0
July	58.4	59.4	64.1	60.1	67.8
August	61.4	61.0	62.8	62.4	64.3
September	59.5	58.0	58.3	62.9	57.8
October	51.4	51.2	50.3	51.7	53.0

[1] U.S. Weather Bureau (1954-58). U.S. Weather Station at Elma is about 10 miles west of McCleary Experimental Forest.

[2] Not available.

part at least, to damage by the November 1955 freeze.[3] Growth subsequent to the freeze was apparently affected by relative damage to competing trees as well as damage to the subject tree, with growth of a few trees being stimulated by improvement in competitive position.

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[3] The cold wave that swept through the Pacific Northwest in November 1955 killed many forest trees. Countless others were damaged but survived (Duffield 1956). In one area in western Washington, 1956 growth rate of codominant trees averaged about half of the 1954-55 growth rate. Radial growth improved thereafter, but magnitude of recovery varied considerably between trees (Reukema 1964).

SUMMARY AND CONCLUSIONS

Measurements over five growing seasons on 20 Douglas-fir, 10 western redcedar, and 10 red alder trees provide information on distribution of growth over the growing season. Changes in radius on the north, east, south, and west sides of 10 Douglas-fir and the north side of all other trees were measured weekly or biweekly with a dial gage dendrometer.

Radial changes measured included true growth plus or minus swelling or shrinking due to moisture, which masked true growth in many instances. On trees measured on four sides, growth rate tended to be greatest on the east side and least on the south. However, trends of radial changes were generally very similar for the north side and the average of four sides.

Generally, most of the true growth of all species apparently took place between mid-April and early September. However, increases in radius started in early April in 1955 and 1958 and not until about May 10 in 1954. Rapid growth continued until mid-September in 1954, but only until late June in 1958. Irregular changes in radius followed the periods of most rapid growth, with some growth taking place in October or later.

The distribution of growth over the season differed considerably from one year to another. Also, shrinkage sometimes exceeded growth, so that percent of "growth" completed by a given date was less than for an earlier date in the same year. The relative seasonal distribution of growth among species, likewise, varied from one year to another.

Much of the yearly variation can easily be linked with weather. That such a relationship cannot be seen for all variations is probably because the combined effect of precipitation, temperature, and wind cannot be properly assessed from available data

The data clearly indicate the importance of avoiding measurements during the growing season, if at all possible, because proportion of growth completed by a given date is difficult to assess. If it is necessary to measure during the growing season, or to work with past measurements made during the growing season, the curves developed in this study can be used as a basis for a crude interpolation of amount of growth completed. The average proportion of growth completed by Douglas-fir by specified dates is shown in table 4. Despite year-to-year differences, averages for other species were nearly the same as for Douglas-fir. The growth curves should be applied with caution, however, because seasonal distribution of growth may vary not only from year to year but also with stand age, density, and location.

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VALUE and EMPLOYMENT associated with PACIFIC NORTHWEST LOG EXPORTS to JAPAN

Thomas C. Adams

Thomas E. Hamilton

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INTRODUCTION

With the rise in log exports from the United States to Japan in recent years, there has been considerable discussion of the impact of these exports on the economy of the Pacific Northwest. One of the many questions raised concerns the comparative amounts of value and employment generated per unit of logs by export in contrast to primary manufacture in domestic mills. The objective of this study is to provide information on this question by determining value and employment generated per thousand board feet in exports and in domestic manufacture for the specific kinds of logs actually exported in the fourth quarter of 1964. Also included are data on species, grade, and size of logs exported during this period.

The study was based on a sample of log exports from seven of the principal ports in western Washington and western Oregon currently exporting logs to Japan. Detailed sampling procedures are described in "Appendix A."

Log export values and employment data were collected from exporting firms, towboat companies, stevedoring firms, steamship companies, and port authorities. Corresponding value data for domestic processing of logs were estimated from price information used in National Forest timber appraisals. Employment requirements for primary log manufacturing were determined from data on file at the Pacific Northwest Forest and Range Experiment Station.

SPECIES, GRADE, AND SIZE OF LOG EXPORTS

Western hemlock was principal export species

As indicated in the tabulation on the next page, western hemlock made up 53.6 percent of the logs exported to Japan during the fourth quarter of 1964. White and noble firs made up 22.8 percent; Douglas-fir, 9.4 percent; and other species, 14.2 percent.[1]

---

[1] The sample volume represents total fourth quarter 1964 log exports of seven exporting firms located at seven different ports.

	Volume, Scribner log scale	
	(Board feet)	(Percent)
Douglas-fir	2,179,640	9.4
Western hemlock	12,427,290	53.6
White firs	2,915,640	12.6
Noble fir	2,369,080	10.2
Sitka spruce	268,120	1.2
Western white pine	130,180	.6
Port-Orford-cedar	2,073,530	8.9
Alaska-cedar	370,180	1.6
Western redcedar	132,480	.6
Mixed species	311,350	1.3
Total	23,177,490	100.0

Forty-six percent of log exports were No. 2 sawmill grade

Grade information was available for approximately 19 million board feet of the sample of exported logs. Of this volume, 46.3 percent were No. 2 sawmill logs, 13.3 percent were No. 3, and 31.1 percent were listed as No. 3 and better. Peelers made up only 3.6 percent, of which none were Douglas-fir. The complete grade distribution was as follows:

Domestic log grade[1]	Volume, Scribner log scale	
	(Board feet)	(Percent)
Peeler or select	688,860	3.6
Special mill	416,680	2.2
No. 1	657,690	3.5
No. 2	8,793,170	46.3
No. 3	2,533,540	13.3
No. 3 and better	5,906,650	31.1
Total	18,996,590	100.0

[1] According to Official Log Scaling and Grading Rules for Puget Sound, Grays Harbor, Columbia River, and Southern Oregon Log Scaling and Grading Bureaus.

Most volume was in logs 14 to 25 inches in diameter

In terms of log numbers, over three-quarters of the sample of exported logs had small-end diameters ranging from 11 to 22 inches (table 1). In terms of log volume, about two-thirds of the exported logs had diameters ranging from 14 to 25 inches. Very few logs in the sample had diameters of 10 inches or less.

Table 1.--Number and volume of logs in a sample of exports to Japan, October through December 1964, by diameter classes

Diameter class (inches)	Logs in sample		Volume, Scribner log scale	
	Number	Percent	M board feet	Percent
8-10	165	7.2	17,420	1.8
11-13	478	20.8	77,840	8.0
14-16	587	25.5	166,180	17.2
17-19	439	19.1	185,860	19.2
20-22	249	10.8	150,790	15.6
23-25	158	6.9	118,390	12.2
26-28	77	3.4	73,520	7.6
29-31	64	2.8	71,930	7.4
32-34	33	1.4	38,860	4.0
35+	49	2.1	67,450	7.0
Total	2,299	100.0	968,240	100.0

VALUE OF EXPORTED LOGS

Figure 1 shows the major components of total value in the log exporting and domestic processing markets. The costs of stumpage, logging, transportation, scaling, and unloading, plus a margin for profit and risk, were considered to be equal in each use. The average value of the logs after these functions were performed was $53.80 per thousand board feet.

Average log export value, free alongside ship, was $73.35 per thousand board feet

The weighted-average value, free alongside ship (f.a.s.), for the sample of export logs was $73.35 per thousand board feet (table 2). The

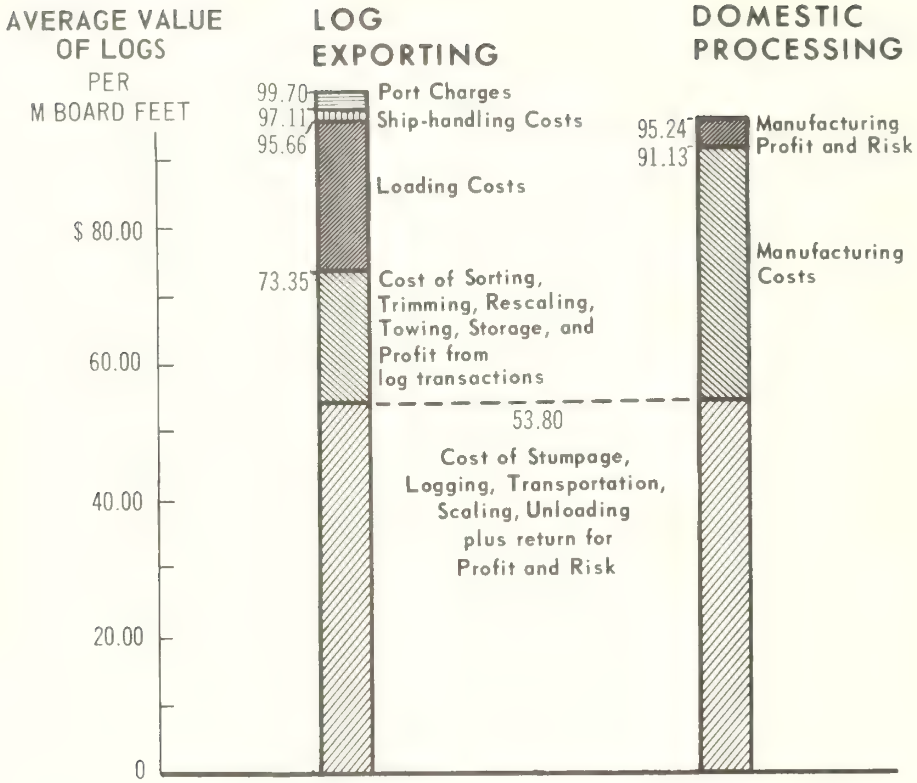

Figure 1.--Value of the export log sample in alternative log markets, Washington and Oregon, October to December 1964.

variation in value among ports was chiefly due to differences in log species, grades, and sizes. In addition, varying amounts of log-processing functions were performed. [2]

Log loading represents the largest cost item

The cost of loading ships represents the largest single addition to f.a.s. log values. The magnitude of these costs varies substantially, depending mainly on the type of ship and the kind of loading equipment used. Special, log-carrying ships, with large hatches and open holds, have considerably lower costs than other types of ships (table 3).

---

[2] An explanation of log processing and other terms is given in "Appendix B."

Table 2.--Volume and value, free alongside vessel (f.a.s.), of sampled log exports to Japan from Washington and Oregon ports, October through December 1964

Port	Log volume	F.a.s. value	
		Total	Average per M bd.ft.[1]
	Board feet[1]	Dollars	Dollars
A	149,880	10,272.66	68.54
B	160,840	10,753.76	66.86
C	236,480	21,151.08	89.44
D	79,180	5,943.47	75.06
E	123,410	8,446.48	68.44
F	187,990	12,219.35	65.00
Total	937,780	68,786.80	73.35

[1] Scribner log scale.

Table 3.--Reported costs of loading logs for export, by type of ship and loading operation, Washington and Oregon, October through December 1964

(Per thousand board feet, Scribner log scale)

Type of operation	Loading costs		
	Low	High	Average
	Dollars		
Special log ship:			
Large cranes	12.14	17.47	14.99
Ship's gear	14.58	19.24	17.74
Other ship:			
Large cranes	17.06	22.27	18.77
Ship's gear	21.83	32.07	25.08
All loading operations[1]	--	--	22.30

[1] Average of all firms reporting, including those that did not show a breakdown.

In table 3, "all loading operations" represents the average loading costs for the entire operation of several firms. Although a wide range was found, most costs tended to be nearer those in the "low" column and averaged $22.30 per thousand board feet of logs.

The data in table 3 show that the use of special log ships is a more important factor in reducing loading costs than is the use of large cranes. Even when ship's gear is used, the cost of loading special log ships is less than that incurred when cranes are used to load ships not built specifically for log transportation.

Ship-handling costs are highly variable but relatively low

Like the cost of loading, the expense of moving ships in and out of port is highly variable; however, this expense is much smaller, ranging from $0.88 to $2.12 per thousand board feet, Scribner log scale (table 4). The range of costs between individual ships may be even greater than is shown here, since these figures represent averages for entire business operations.

Table 4.--Reported costs of handling log ships, Washington and Oregon, October through December 1964

(Per thousand board feet, Scribner log scale)

Type of cost	Handling costs		
	Low	High	Average
	Dollars		
Pilotage	0.24	0.38	0.30
Customs tax	.19	.23	.21
Other customs fees	.04	.04	.04
U.S. Immigration, Public Health, and Plant Quarantine	.02	.06	.04
National Cargo Bureau	.06	.06	.06
Line handling	.08	.13	.09
Towage	.17	.41	.26
Total	.80	1.31	1.00
Miscellaneous costs	.08	.81	.45
All costs	.88	2.12	1.45

Port charges average $2.59 per thousand board feet

Port charges include wharfage, dockage, and service charges. These may be fixed per ton, per thousand board feet, or per time period. They differ, depending on whether logs are loaded from the water or from the dock, as follows:

	Loaded from water	Loaded from dock	Average
	(Per M board feet, Scribner log scale)		
Wharfage	$0.75	$1.50	$1.13
Dockage	.60	.60	.60
Service charge	.39	1.33	.86
Handling charge[1]	--	3.57	--
Total	1.74	7.00	2.59

[1] In addition to other costs, there may be a charge for cargo handled by the port, if loaded from the dock. This handling charge is included in the f.a.s. values.

Average export value on board ship was $99.70 per thousand board feet

The average value of the log export sample, loaded aboard ship, was $99.70 per thousand board feet, Scribner rule (table 5). Average values at individual ports ranged from $91.64 at port F to $114.52 at port C.[3]

Average manufacturing cost calculated as $37.33 per thousand board feet

Forest Service timber appraisal methods were used to calculate an average manufacturing cost of $37.33 per thousand board feet and a margin for profit and risk of $4.11 for the logs in the sample (fig. 1). These costs are based on the primary lumber, plywood, and chip products, f.o.b. mill, that could be recovered if the logs were processed domestically.

---

[3] Data from a seventh port in the sample, Coos Bay, is omitted from this section because the sample from this port was composed entirely of Port-Orford-cedar, a species with unusually high export value and one not shipped from any other port.

Table 5.--Value of the export log sample in alternative log markets, Washington and Oregon, October through December 1964, by sampled ports

Port	Log volume	Value in log export		Value in domestic manufacture[1]	
		Total	Average per M bd. ft.[2]	Total	Average per M bd. ft.[2]
	Board feet[2]	Dollars	Dollars	Dollars	Dollars
A	149,880	14,318.24	95.53	14,344.78	95.71
B	160,840	14,991.32	93.21	14,554.71	90.49
C	236,480	27,082.39	114.52	24,352.76	102.98
D	79,180	7,945.46	100.35	7,418.17	93.69
E	123,410	11,929.42	96.66	11,160.87	90.44
F	187,990	17,227.10	91.64	17,478.68	92.98
Total and average	937,780	93,493.93	99.70	89,309.97	95.24

[1] Imputed log value calculated from wholesale prices of primary manufactured products, f.o.b. mill. It does not reflect the extra value of special items and remanufactured products.

[2] Scribner log scale.

Sample logs valued slightly higher for export

The average value of products that could be obtained by domestically processing the log export sample was $95.24 per thousand board feet (table 5).[4] This figure was slightly lower than the value attained for these logs in the export market. However, in two cases, ports A and F, domestic processing shows a greater value.

---

[4] Value in domestic manufacture was determined by applying end-product selling values used in Region 6 National Forest timber appraisals. The method of determination is shown in "Appendix A."

EMPLOYMENT IN LOG EXPORTING AND DOMESTIC PROCESSING

Figure 2 shows the man-hours required per thousand board feet of logs in the log-exporting and the domestic-processing markets. Employment for logging and log transportation is the same for both markets, amounting to 4.46 man-hours per thousand board feet.

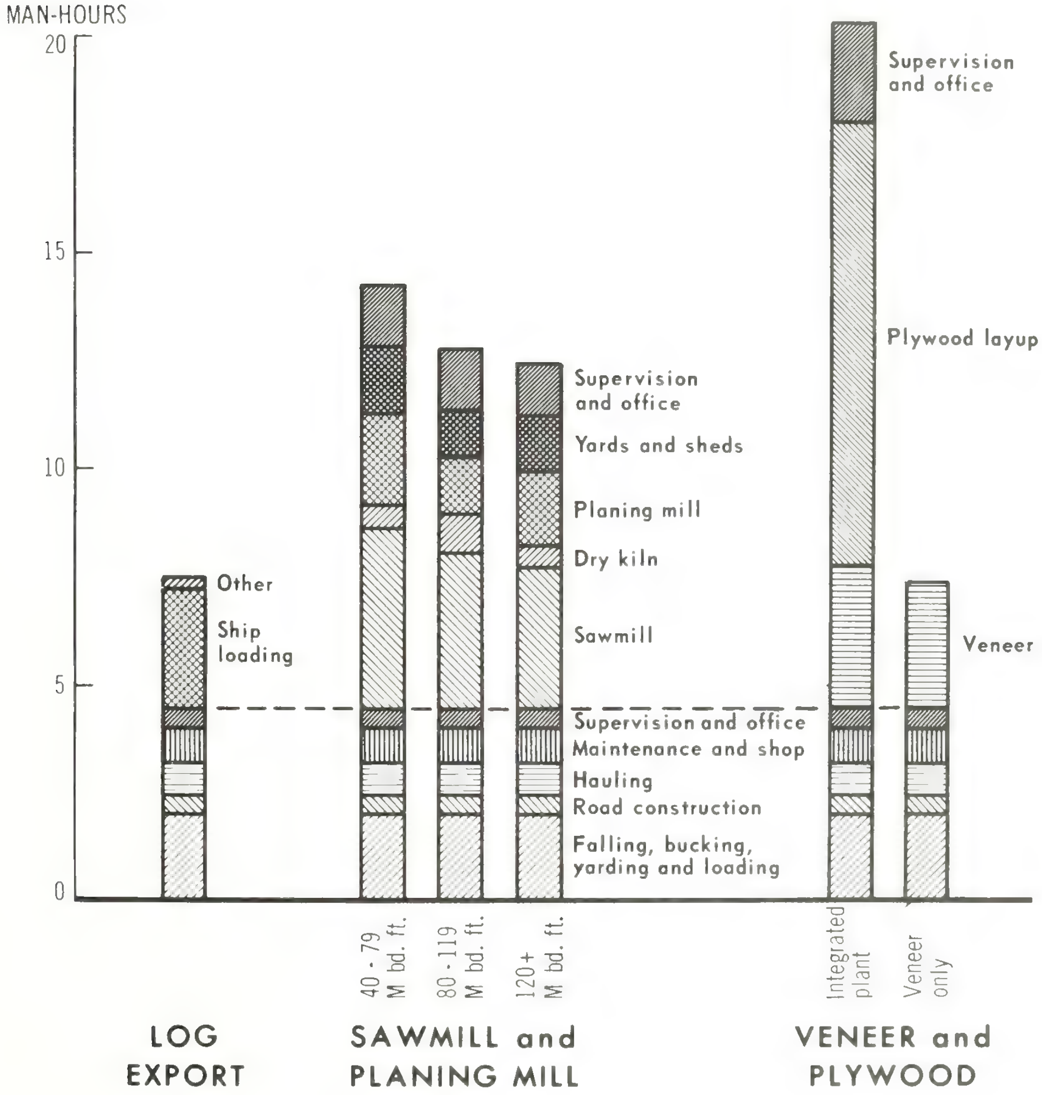

Figure 2.-- Employment per thousand board feet of logs in log exporting and domestic log manufacturing.

Log exporting requires 3.01 man-hours per thousand board feet

Average employment requirements for log exports were 3.01 man-hours per thousand board feet of logs. Since log-exporting functions are generally performed by a number of different firms, this figure is based on an estimate of each firm's employment contribution.

The average employment requirement for all kinds of log-loading operations was 2.76 man-hours per thousand board feet (table 6). The use of special log-carrying ships and large shore-based or floating cranes has materially lowered the amount of labor needed to load logs for export.

On a per-thousand-board-foot basis, only a small amount of employment was required for the exporting functions of buying and selling, log preparation, extra scaling, rafting and towing, port operation, ship handling, and shipping agents' services. Although it was difficult to measure the labor requirements for these activities, their contribution to total employment was estimated at 31 man-days per million board feet, or 0.25 man-hour per thousand board feet.

Table 6.--Man-hours required per thousand board feet, Scribner log scale, in loading logs for export, by type of ship and loading operation, Washington and Oregon, October through December 1964

Type of operation	Low	High	Average
Special log ship:			
Large cranes	1.11	3.38	2.03
Ship's gear	1.65	3.76	2.56
Other ships:			
Large cranes	1.88	4.47	2.69
Ship's gear	2.35	6.58	3.76
All types (average)	1.75	4.55	2.76

More employment associated with domestic manufacture

The average labor requirements for log exporting were compared with those for domestic manufacturing in western Washington and western Oregon sawmills and plywood plants, as developed from a recent Forest Service study.[5]

Employment requirements for domestic lumber manufacture ranged from 8.01 to 9.76 man-hours per thousand board feet of logs (table 7, fig. 2). These were well above the 3.01 man-hours per thousand board feet in log exporting.

The above employment requirements for domestic lumber manufacture are for surfaced, kiln-dried lumber. However, some mills produce only surfaced, green lumber; employment requirements in these mills would be somewhat less in all functions except the sawmill itself.

Table 7.--Man-hours required per thousand board feet, Scribner log scale, in domestic lumber manufacture, western Washington and western Oregon

Function	Sawmill-size class[1]		
	40-79	80-119	120 and over
Sawmill	4.16	3.58	3.00
Dry kiln	.56	.91	.80
Planing mill	2.12	1.30	1.69
Yards and sheds	1.50	1.08	1.31
Supervision and office	1.42	1.41	1.21
Total	9.76	8.28	8.01

[1] Thousand board feet per 8-hour shift.

---

[5] Smith, Richard C. Manpower requirements in the wood-products industries of Oregon and Washington, 1950-63. (In preparation for publication, Pac. NW. Forest & Range Expt. Sta., U.S. Forest Serv.)

Employment requirements in plywood manufacture were:

	Man-hours per M board feet, Scribner log scale
Integrated plants:	
Veneer production	3.35
Plywood layup	10.21
Supervision and office	2.29
Total	15.85
Veneer plants	2.94

Employment requirements for integrated plywood plants were several times those for log exporting. However, employment in nonintegrated veneer plants was slightly less than in log exporting.

APPENDIX A

Source of data for the export market

The information in this report was obtained from log scaling records for a sample of logs actually exported during the period October through December 1964.

A stratified random sample of 7 ports, 4 in Washington and 3 in Oregon, was chosen from the 14 principal ports currently exporting logs to Japan from the two States. One shipper was chosen at random from each of these ports, from whom records of log volume by species and grade were obtained for their entire October through December 1964 exports to Japan. In addition, species, grade, diameter, and f.a.s. log values were obtained from each shipper for a smaller sample of 100 to 500 export logs.

Loading costs, port charges, ship-handling costs, and employment requirements were obtained from towboat companies, stevedoring firms, steamship companies, exporters, and port authorities. The data from these sources were aggregated to determine average costs and employment in log exporting.

Determination of value in domestic processing

Value in domestic manufacture was determined by applying primary-product selling values used in National Forest timber appraisals. These values are for lumber, plywood, and chip use, depending on how each species, grade, and size of log would be classified in the appraisal.

Table 8 shows this method of value determination, using No. 2 western hemlock logs as an example. The imputed value of the logs in this sample was $89.46 per thousand board feet, log scale. A similar calculation was made for all species and grades of logs in the export sample, and the results were aggregated to obtain an average domestic value for the entire sample volume.

Table 8.--Imputed value of a sample of No. 2 hemlock logs in domestic manufacture, by log diameter and volume

Log diameter (inches)	Board-foot volume[1]	1963 primary-product selling value, per M board feet[1]	Total 1963 selling value	Adjustment to 1964 3rd qtr. price[2]	Value of chippable residue at $4.69 per M board feet[1]	Total log value	Average log value per M board feet[1]
		Dollars					
14-16	13,600	84.00	1,142.40	1,159.54	63.78	1,223.32	89.95
17-19	18,580	84.00	1,560.72	1,584.13	87.14	1,671.27	89.95
20-22	11,980	84.00	1,006.32	1,021.41	56.19	1,077.60	89.95
23-25	10,470	82.00	858.54	871.42	49.10	920.52	87.92
26-28	1,030	82.00	84.46	85.73	4.83	90.56	87.92
29-31	1,560	81.00	126.36	128.26	7.32	135.58	86.91
Total	57,220	--	4,778.80	4,850.49	268.36	5,118.85	89.46

Source: Product values and adjustment factor taken from Region 6 U.S. Forest Service Handbook on Timber Appraisal (FSH2 chapter 2425-R6).

[1] Scribner log scale.

[2] By factor of 1.015.

APPENDIX B

Definition of terms

Log-processing costs--include all expenditures for sorting, scaling, towing, bucking, and trimming logs in preparation for their export. These charges are included in the f.a.s. value of the logs.

Loading costs--include (1) wages of supercargo and (2) stevedoring, including wages, overtime and vacation pay, payroll taxes, health benefits, accident insurance, crew transportation, portable winches, crane rental, and services of a work boat in the water.

Port charges--include all payments to the ports for wharfage, service charges, and dockage.

Ship-handling costs--include (1) the expenses incurred in moving the ship into and out of the port and (2) dollar payments for maintenance of the ship and crew while in port and supplies for the return voyage.

Wharfage--is the charge by the port for use of its cargo-holding facilities.

Handling charge--is the charge levied by the port authority for handling the cargo on the dock.

Service charge--is the charge for use of port services such as lighting and personnel services.

Dockage--is the charge for the ship's berth.

Special log ship--is a ship built specifically for log transportation.

Other ships--are ships intended for transporting general cargo.

Pilotage--is the charge for guiding a ship in or out of port.

Customs tax--is the charge for a ship's clearance and entry into the country.

Customs fee--is the payment for services of a customs broker who assesses the tax.

U.S. Immigration, Public Health, and Plant Quarantine charge--is the charge for these inspections; a charge is made for overtime work only.

National Cargo Bureau--is a Government agency which determines whether cargo is loaded properly to insure safety and stability.

Line-handling charge--is the charge for services of mooring the ship to the dock and casting off.

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MANPOWER USE in the WOOD-PRODUCTS INDUSTRIES of OREGON and WASHINGTON

1950 - 1963

by **Richard C. Smith**

and **Donald R. Gedney**

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RESEARCH PAPER PNW 28
1965

FOREWORD

This study of employment in the wood-products industries during the period 1950 to 1963 was undertaken in response to the need for a sound, up-to-date basis for projecting the future development of the Pacific Northwest forest economy. This need became particularly apparent when the Bonneville Power Administration undertook its comprehensive study entitled "Pacific Northwest Economic Base Study for Power Markets." In order to develop this information, Bonneville Power Administration contracted with the Station and provided the funds necessary for an appraisal of output and employment in the forest-products industry.

Dr. Richard C. Smith temporarily joined our staff while on sabbatical leave from the University of Missouri forestry staff. This cooperation by the University of Missouri is very much appreciated. Donald R. Gedney is resource analyst in our Forest Survey project.

The Oregon Department of Employment and the Washington Employment Security Department supplied data on employment in the wood-using industries. The Western Wood Products Association, American Plywood Association, and many industrial firms supplied data on volume of wood processed, hours of labor expended, and other useful information. Labor and industry leaders, foresters, and numerous other individuals gave their suggestions and appraisals of trends in the industry which were invaluable in the analysis of the statistical data. All of this cooperation is greatly appreciated.

Philip A. Briegleb

Philip A. Briegleb, Director
Pacific Northwest Forest and Range
Experiment Station

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SUMMARY

In Oregon and Washington during 1963, 138,900 persons were employed by the wood-using industries. This was more than one-third of all manufacturing employment. During the 14 years from 1950 through 1963, employment in the wood-using industries declined 11 percent. This overall reduction resulted from various changes in the separate industries making up the total. It is the result of a complex of factors including changes in total production, increases in the efficiency of manpower, and changes in kinds of products and in the amount of product refinement. Logging employment decreased by 5,000 workers, or about 18 percent, although the volume of logs harvested increased 14 percent. Sawmill employment decreased 44 percent, or by 32,300 workers; however, lumber production dropped only 2 percent. The decrease of 900 workers employed in miscellaneous wood manufacturing resulted largely from a declining output of millwork and boxes. A threefold increase in plywood production was accompanied by an increase in employment of 81 percent, or 14,800 persons; in the paper and allied products industries, production doubled but employment increased by only 33 percent, or 6,600.

In 1963, the average number of employees per unit of annual wood input was:

Industry	Number of employees
Logging (per MM bd. ft.[1])	1.41
Sawmills and planing mills (per MM bd. ft.[1])	3.60
Veneer and plywood (per MM bd. ft.[1])	7.31
Paper and allied products, 1962 (per M cords of wood used)	3.48

[1] International 1/4-inch rule.

Manpower use, per unit of wood input as shown above, decreased substantially in these industries in the years between 1950 and 1963:

Industry	Percent
Logging	26
Sawmills and planing mills	42
Veneer and plywood	50
Paper and allied products (1962)	36

These reductions in manpower use resulted from plant mechanization--particularly for handling of materials, increased worker skill, and the use of more efficient machinery of greater capacity--and development of a mix of products that is processed with fewer workers.

INTRODUCTION

The wood-products industries comprise a large sector of the manufacturing economy of Oregon and Washington. They employ one-tenth of the entire labor force. In many communities, logging contractors and manufacturers of wood products offer the only source of employment other than retail trade and services. Trade and service businesses prosper because of employment and activity in these industries. Almost 139,000 persons worked for wood-products industries in 1963, more than one-third of the number of employees in all manufacturing. They received $827 million in wages.

The purpose of this study is to determine current employment in the major wood-products industries in Oregon and Washington, to indicate trends between 1950 and 1963 in total manpower use and in employment per unit input, and to show variation between 1957 and 1961 in monthly employment.

The statistics averaged in this report encompass wide variation in individual plants. Mills differ in number of products manufactured, their sizes and grades, and the extent of finishing or remanufacturing. Firms manufacturing essentially the same products often differ in the kinds of equipment operated and degree of mechanization. At individual plants, worker ability and performance, age and condition of machines, transportation, timber supply, and product specifications may be different than for other manufacturers.

The employment data, upon which the bulk of the statistics is based, include only workers directly employed by wood-using industries and as recorded by the Washington Employment Security Department or the Oregon Department of Employment. No attempt was made to include other less direct employment such as for service to equipment used in wood-products industries.

In addition, a survey was made of randomly selected firms within each industry group to show manpower use by job function. Data were obtained from a mailed questionnaire or by personal interview. Information supplied by individual firms was weighted by volume of wood processed to arrive at average manpower use. The total manpower use for each industry, obtained by this sampling, was found to be in general agreement with that based on published information for all firms by State subarea.

TOTAL EMPLOYMENT IN THE WOOD-PRODUCTS INDUSTRIES

Employment in 1963

In 1963, more than one-half of the manufacturing labor in Oregon was employed by the forest-products industries.[1] In Washington, with a more diversified industrial base, one-fourth of the employees in all manufacturing worked in the wood-products industries.

For the two States, 17 percent of the 138,900 employees in the forest-products industries were engaged in supplying logs to mills and plants (table 1). Close to 42,000 persons, 30 percent, worked for sawmill and planing mill firms, and 24 percent worked for veneer and plywood companies. Paper and allied products firms employed 19 percent, and about 10 percent were engaged in miscellaneous wood manufacturing. More than one-half of the workers in miscellaneous wood manufacture and 72 percent of those in paper and allied products were employed in Washington (table 2). In the other major forest-products industries, almost two-thirds of the workers were employed in Oregon, including 73 percent of all veneer and plywood employees.

Table 1.--Average employment in manufacturing and wood-using industries in Oregon and Washington, 1963

Industries	Employees	Percent of wood-using industries	Percent of all manufacturing industries
Wood-using:			
Logging	23,669	17.0	--
Sawmills and planing mills	41,772	30.1	--
Veneer and plywood	33,040	23.8	--
Paper and allied products	26,170	18.8	--
Miscellaneous wood manufacturing	14,274	10.3	--
Total	138,925	100.0	37.6
All other manufacturing	230,395	--	62.4
Total all manufacturing	369,320	--	100.0

---

[1] Statistics were compiled from monthly employment data provided by the Oregon Department of Employment and the Washington Employment Security Department. The nature of data, method of compilation, and definition of industries are described later in the report.

Table 2.--Average employment in wood-using industries in Oregon and Washington, by State subregion, 1963

Industries	Oregon		Washington		Total
	Western	Eastern	Western	Eastern	
	Number				
Logging	11,054	1,503	9,514	1,598	23,669
Sawmills and planing mills	18,554	7,407	11,048	4,763	41,772
Veneer and plywood	1/24,007		1/9,033		33,040
Paper and allied products, total	1/7,366		17,740	1,064	26,170
Pulp	229	--	1/2,311		2,540
Paper, paperboard, building paper and building board	1/5,412		1/13,512		18,924
Paperboard containers and boxes	665	--	1/1,751		2,416
Other paper and board products	1,060	--	1/1,230		2,290
Miscellaneous wood manufacturing, total	5,302	1,267	1/7,705		14,274
Special product sawmills	788	--	2,351	40	3,179
Millwork	1,787	1,050	2,627	621	6,085
Prefabricated structures and parts	1/904		612	23	1,539
Wooden containers	445	58	408	129	1,040
Wood preserving	1/460		1/408		868
Other wood products	1/1,077		394	92	1,563

1/ "Eastern" and "western" combined to avoid disclosure of employment by individual firms.

In all wood-using industries combined, 55 percent of the workers were employed in Oregon and 45 percent in Washington; table 2 shows 1963 employment within each State.

Trends in Employment, 1950-63

Employment down 12 percent

Average annual employment in all wood-using industries decreased from 156,000 persons in 1950 to 139,000 in 1963 (fig. 1). Periods of business recession are reflected in low employment during 1954, 1957, and 1958. Peak employment occurred in 1951, 1955, and 1959. Employment in Oregon wood industries was consistently higher than in Washington during this period. The number of workers declined in both States, and the losses occurred at a slightly greater rate in Washington.

Decrease in sawmill employment largest

The largest decrease in employment in the forest-products industries during 1950 to 1963 was in the manufacturing and processing of lumber (fig. 2 and table 3). In 14 years, employment in sawmills and planing mills decreased from 74,000 to 41,800. This decrease took place between 1950 and 1961. Employment stayed at about the same level in 1961, 1962, and 1963.

Plywood, pulp and paper employment up

The veneer and plywood industry recorded a substantial gain of 81 percent between 1950 and 1963. The only other major wood industry increasing was the pulp and paper industry with a more moderate gain of 33 percent. In both of these industries, the gain in employment was relatively steady and constant during the period.

Table 3.--Employment in the major wood-products industries in Oregon and Washington, 1950 and 1963

Industry	1950	1963	Change
	Number		Percent
Logging	28,664	23,669	-17
Sawmills and planing mills	74,053	41,772	-44
Veneer and plywood	18,261	33,040	+81
Miscellaneous manufacturing	15,199	14,274	-6
Pulp and paper	19,605	26,170	+33
Total	155,782	138,925	-11

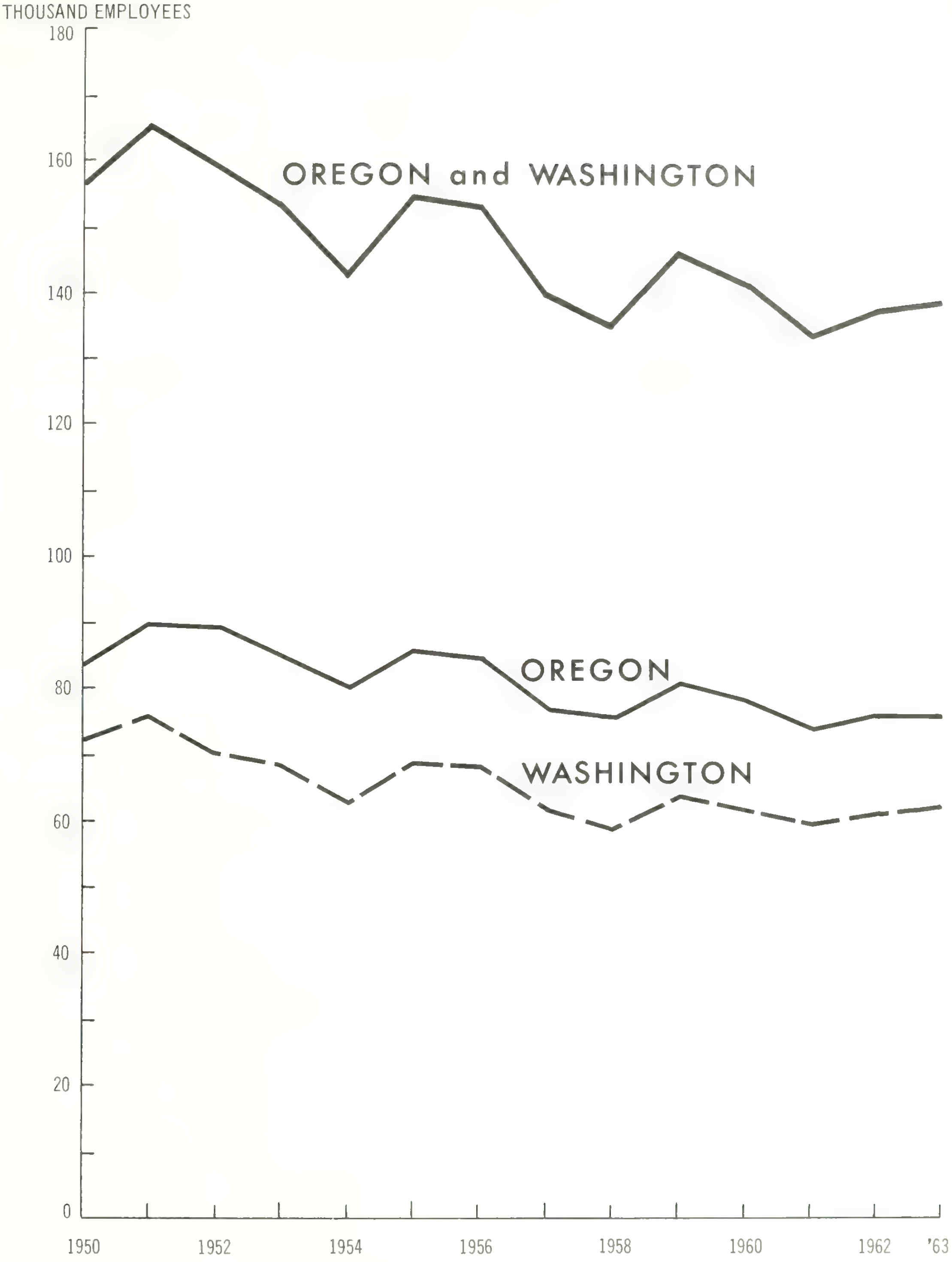

Figure 1.--Average annual employment in all wood-using industries in Oregon and Washington, 1950-63.

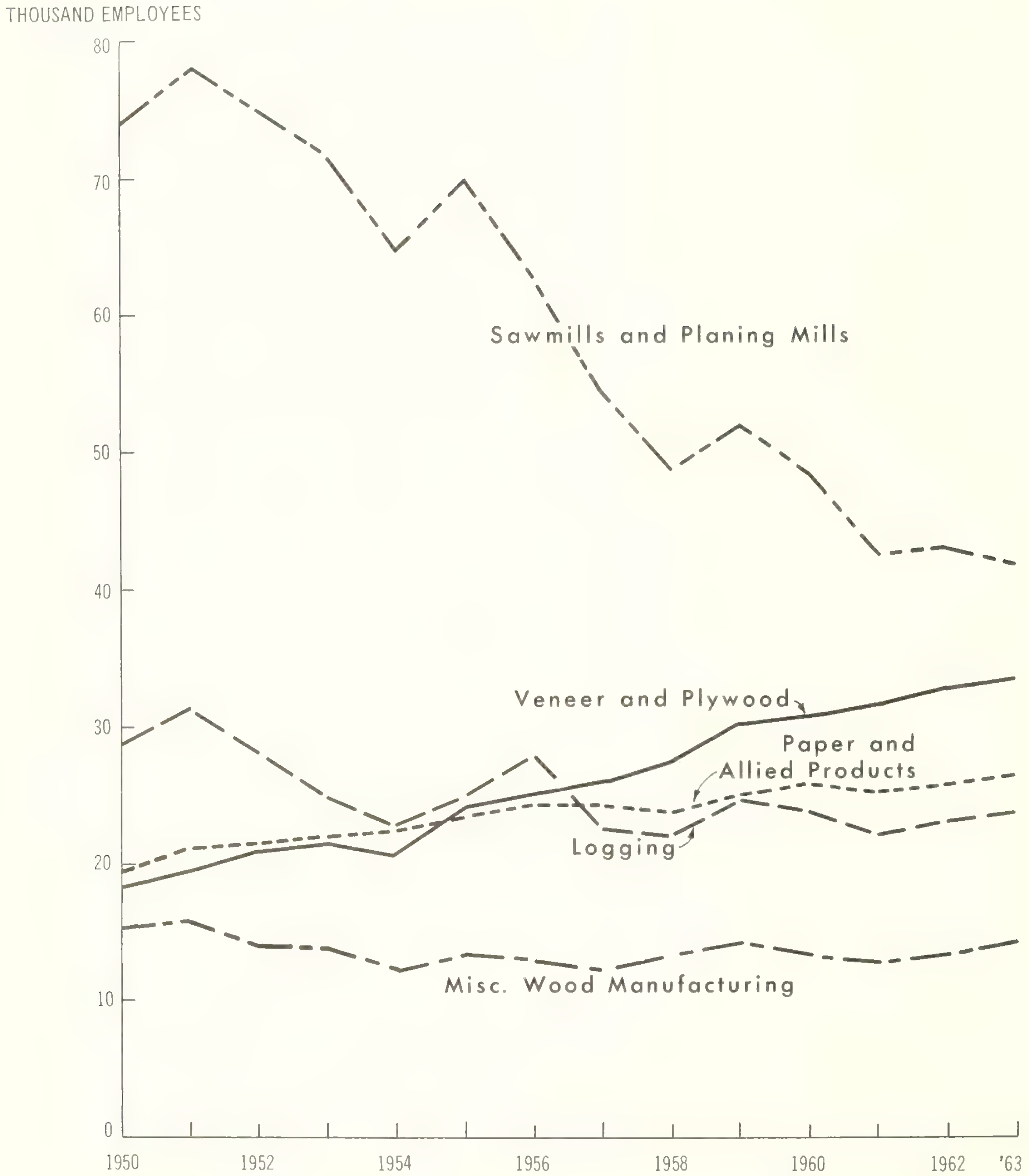

Figure 2.--Average annual employment by wood-using industries in Oregon and Washington, 1950-63.

EMPLOYMENT IN THE LOGGING INDUSTRY

Trends in Annual Employment Down

Employment loss greatest west of the Cascades

Employment in the logging industry in Oregon and Washington decreased from about 29,000 persons in 1950 to 24,000 in 1963. Most of this reduction took place on the west side of the Cascade Range, with the greater loss occurring in western Washington (fig. 3). Although changes in employment were not great east of the Cascades, some decrease in logging employment took place in eastern Oregon but a slight gain was registered in eastern Washington.

A comparison of the log production statistics, shown in the small inset graph in figure 3, with employment shows that production and employment do not always follow the same trend. In western Oregon, both employment and log production decreased; in western Washington, employment dropped although log production stayed relatively level. In eastern Oregon, employment decreased and log production increased, and in eastern Washington, both log production and employment increased.

Annual manpower use in logging decreasing

Average manpower use for logging during the 14 years was different among State subregions (fig. 4). Both western Washington and eastern Washington were higher in manpower use per unit volume logged than the two Oregon subregions. Differences in rate of change were also broadly apparent, with western Oregon showing only relatively moderate decline over time compared with the more pronounced downward trend in other State subregions.

Manpower used for logging in 1963 in western Washington was 1.73 workers per million board feet of logs harvested, 35 percent higher than in western Oregon.

Manpower Use by Job Function

Almost half annual manpower use expended in woods

Almost one-half of the labor effort in logging was actually expended in the woods in the processes of falling, bucking, yarding, and loading (table 4). Hauling and other jobs, including maintenance and shopwork, took another 36 percent. The number of workers was significantly greater on the west side than on the east side for all job functions except hauling, but the percentage distributions of total manpower among the job functions were similar. The manpower use shown in table 4 for road construction and maintenance is undoubtedly too low for constructing a major access road. However, this average figure includes many logging operations that do not require much road work in relation to timber volume harvested.

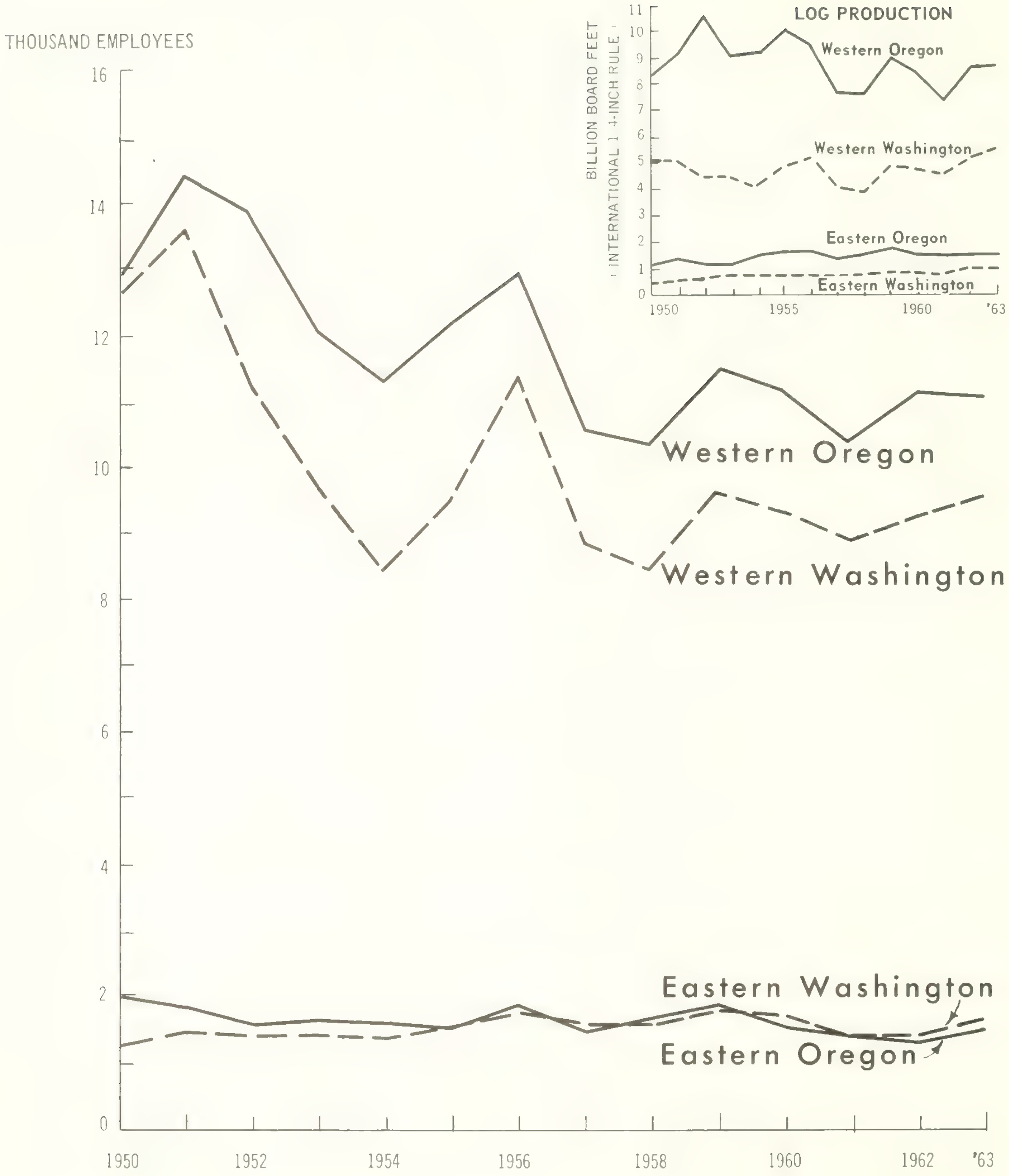

Figure 3.--Average annual employment in logging and log production in Oregon and Washington, by State subregion, 1950-63

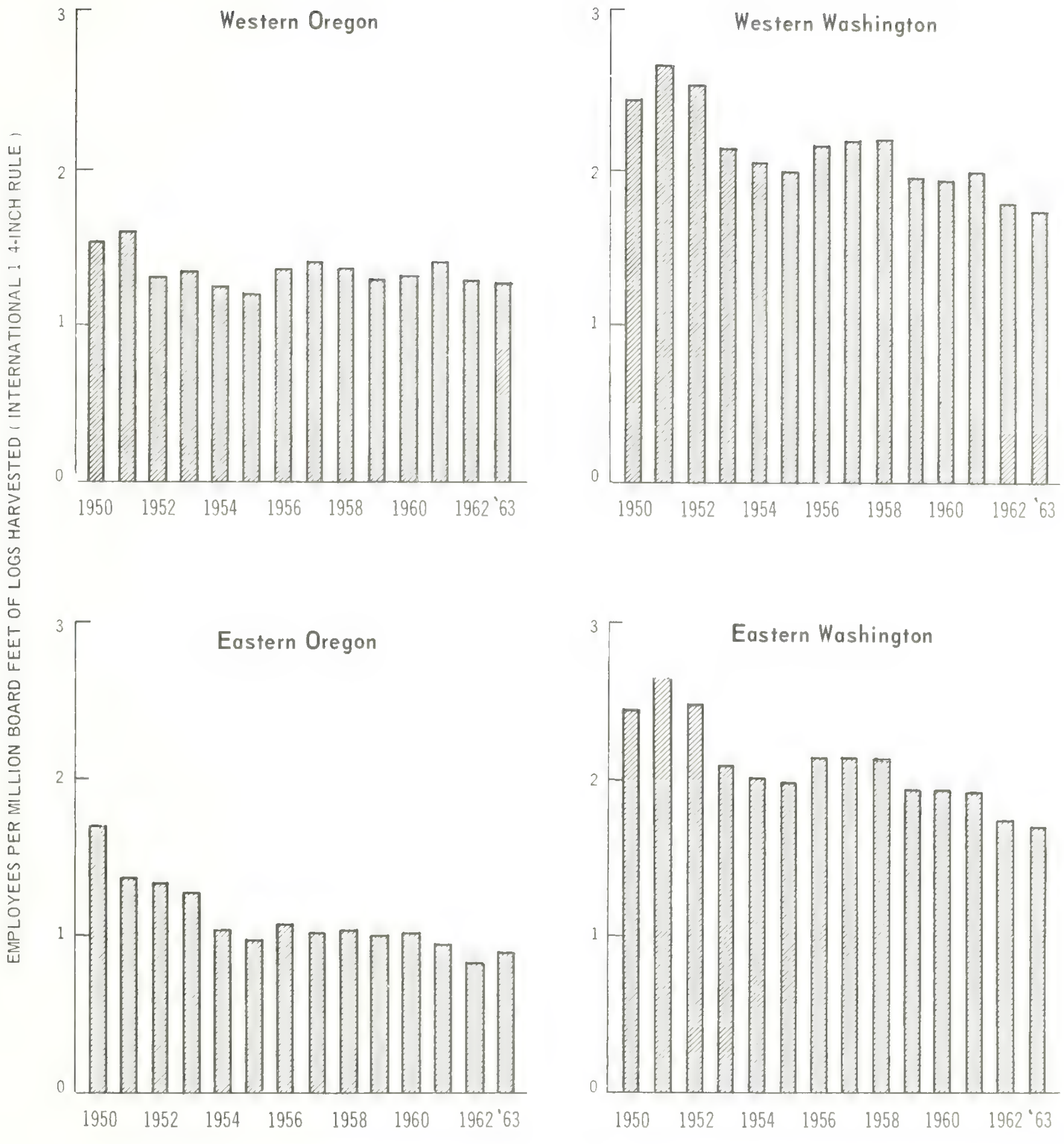

Figure 4.--Average annual employment per million board feet of logs (International 1/4-inch rule) harvested in Oregon and Washington, by State subregion, 1950-63.

Table 4.--Logging manpower use, by job function and number of employees per million board feet of logs harvested annually in Oregon and Washington and by subregion, 1962

Job function	West side[1]		East side[2]	
	Number	Percent	Number	Percent
Falling, bucking, yarding, and loading	1.06	47	0.87	48
Road construction and maintenance	.21	9	.14	7
Hauling	.38	17	.46	25
Supervision and clerical	.19	8	.11	6
Other, including maintenance and shop	.43	19	.26	14
Total	2.27	100	1.84	100

Source: Data supplied by 37 firms that harvested 648 million feet of logs, Scribner scale.

[1] West of the Cascade Range.

[2] East of the Cascade Range.

Output per man-hour by job function

Data supplied by the firms sampled were also compiled to show current average rates of output per man-hour for production workers by job function during 1962 (table 5). Maintenance employees, overhead, and others not directly engaged in the production process were not included by job function but were included in the computation of the overall rate of output per man-hour for all employees on all job functions.

The data shown in table 5 of output of logs per man-hour by job function should not be used as a basis of comparison of differences for specific job functions between the west and the east side. Although part of the differences are real and reflect differing output per man-hour, these are obscured by the use of local log rules that measure the same volume differently.[2] On the east side, the use of a "short log" Scribner rule[3] results in higher volume estimates than if the same log were measured by the "long log" scaling practice common to the west side. Thus, the data shown in this table, and in other presentations in this report showing values for both the east and west side and using log volumes, Scribner scale, as a basis for comparison, do not measure relative efficiencies in worker output between the east and west side. Instead, they simply provide a measure of output in units of production unique to the particular area.

Table 5.--Logging output of logs per man-hour in Oregon and Washington, by job function and subregion, 1962

Job function	West side[1]	East side[2]
	-- Board feet, Scribner rule --	
Falling, bucking, yarding, and loading	483	586
Hauling	1,342	1,095
All employees, all job functions	224	277

Source: Data supplied by 37 logging firms that harvested 648 million feet of logs, Scribner rule.

[1] West of Cascade Range.

[2] East of Cascade Range.

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[2] Staebler, George R. Long logs or short logs with the Scribner scale. Timberman 54(10): 66, 68, 70, illus. 1953.

[3] In general, where results of industry canvasses or association studies are reported, the log rule used is not converted to the standard Forest Survey unit of measurement of board-foot volume, the 1/4-inch International rule. The Scribner scale is approximately 80 percent of the comparable International 1/4-inch volume on the west side and 91 percent on the east side. In other instances, such as the general figures of production shown in the inset graph in figure 3, the volume is shown in the 1/4-inch International rule.

Logging output per man-hour has increased most in pine region

Logging output, per man-hour of production workers employed by firms reporting to the Western Wood Products Association, is shown in figure 5. An increase per man-hour on west-side operations from 175 feet, Scribner scale, in 1950 to 235 feet in 1962 is substantial, but logging output per man-hour in the pine region increased from 260 feet in 1950 to 470 feet in 1961. Data for the pine region include reports from portions of 12 Western States, a broad heterogeneous area, here referred to as the pine region and used to reflect trends in eastern Oregon and eastern Washington. Data reflecting west-side conditions include some mills in California but represent well the conditions in western Oregon and western Washington.

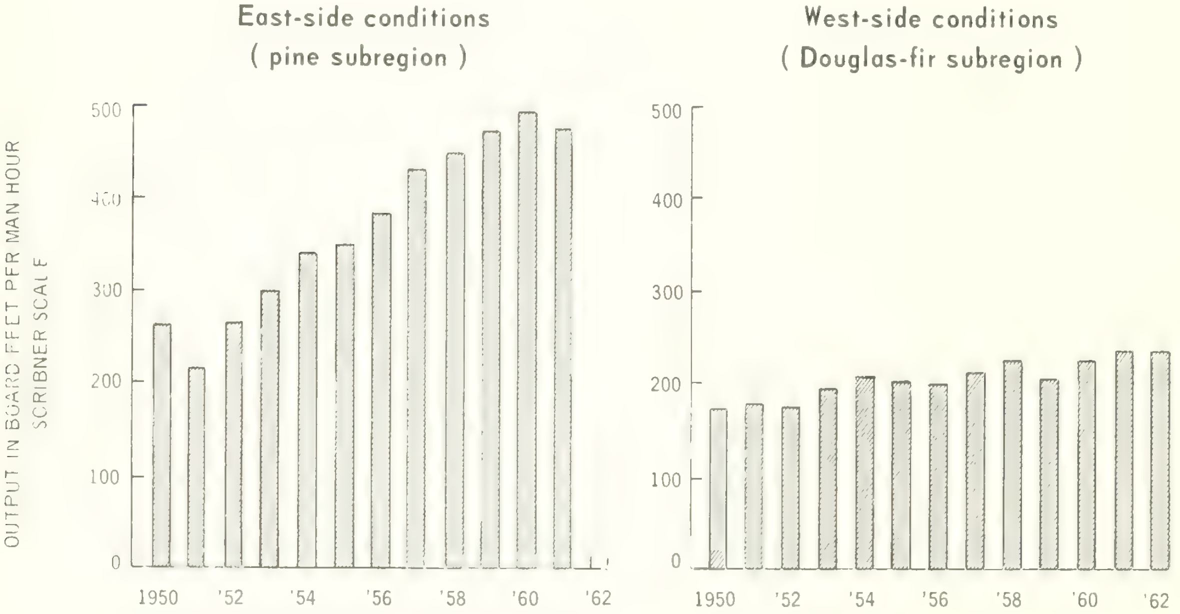

Figure 5.--Logging output per man-hour of firms reporting to Western Wood Products Association, by subregion, 1950-62

The association data differ from those previously shown because they include production workers only. According to the 1958 Census of Manufactures, for the Pacific Northwest the proportion of production workers in logging to all employees was 89 percent. Thus, output per man-hour based on association data is higher than if the ratios were based on all employees.

EMPLOYMENT IN SAWMILLS AND PLANING MILLS

Employment in Sawmills Down 44 Percent

Western Oregon has greatest reduction

Employment statistics by industry groups show where gains and losses occurred (fig. 2). The largest change took place in sawmills and planing mills, a decrease from 74,000 in 1950 to 41,800 in 1963, or 44 percent. Unfavorable years for the lumber industry are reflected in low employment during 1954, 1957, and 1958. The decrease in employment was much greater than the decrease in lumber production, which was 2 percent during the same period, from 11.8 billion board feet in 1950 to 11.6 billion in 1963 (fig. 6). Two-thirds of the reduction in sawmill and planing mill employment occurred in western Oregon, where the number of workers decreased from 39,000 to 18,600. Western Washington sawmill employment dropped somewhat less, from 20,000 to 11,000. In eastern Oregon, the decrease was from 10,500 to 7,400; however, in eastern Washington little change occurred. All of these changes are not directly associated with changes in local production. This can be seen by comparing the production data in the inset graph of figure 6 with the employment data. For example, western Oregon 1963 employment was 48 percent of that in 1950, but 1963 lumber production was 89 percent of that in 1950. Similarly, western Washington 1963 employment was 55 percent of that in 1950, but lumber production was 84 percent of 1950 output. Although lumber production increased in eastern Oregon and eastern Washington, employment did not.

Sawmill manpower use per unit input requires fewer employees

Manpower use, by all of the sawmills and planing mills, decreased from approximately 6.2 employees per million board feet of logs[4] used in 1950 to about 3.6 workers in 1963. Despite relatively wide annual fluctuations in employment per million board feet of logs used, a reduction in manpower use occurred in all subregions (fig. 7). For the industry as a whole, manpower use per unit of wood used was reduced 42 percent in the past 14 years.

Manpower use in Oregon plants generally lower

In 1963, sawmills and planing mills in western Washington used 37 percent more labor per unit input than mills in western Oregon. East of the Cascade Range in the two States, the sawmill manpower needs are more nearly alike. However, Washington sawmill employment per unit on both sides of the Cascades is higher than in Oregon.

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[4] International 1/4-inch rule. Log scale and lumber grade are assumed to be equal.

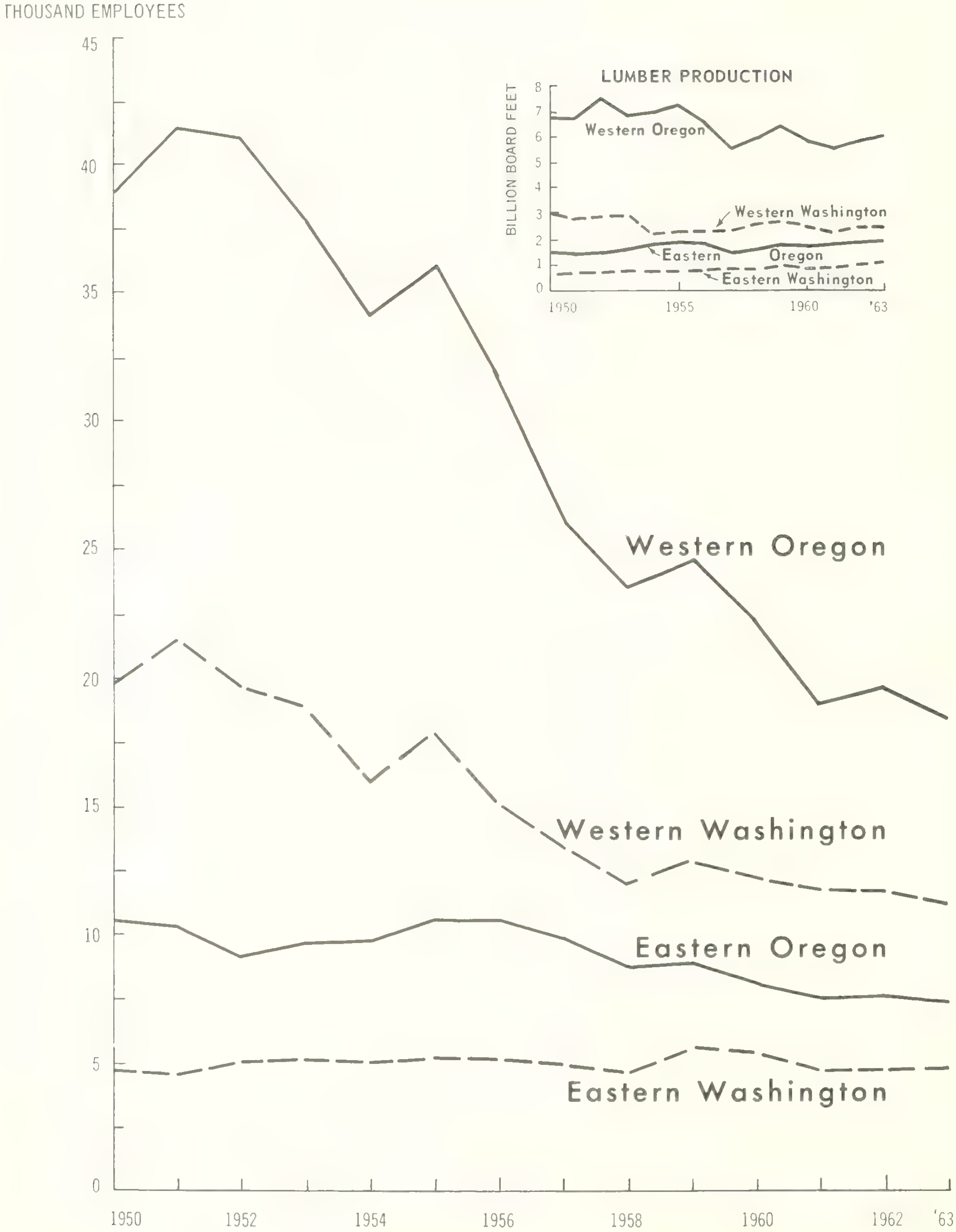

Figure 6.--Average annual employment and lumber production in sawmills and planing mills in Oregon and Washington, by State subregion, 1950-63.

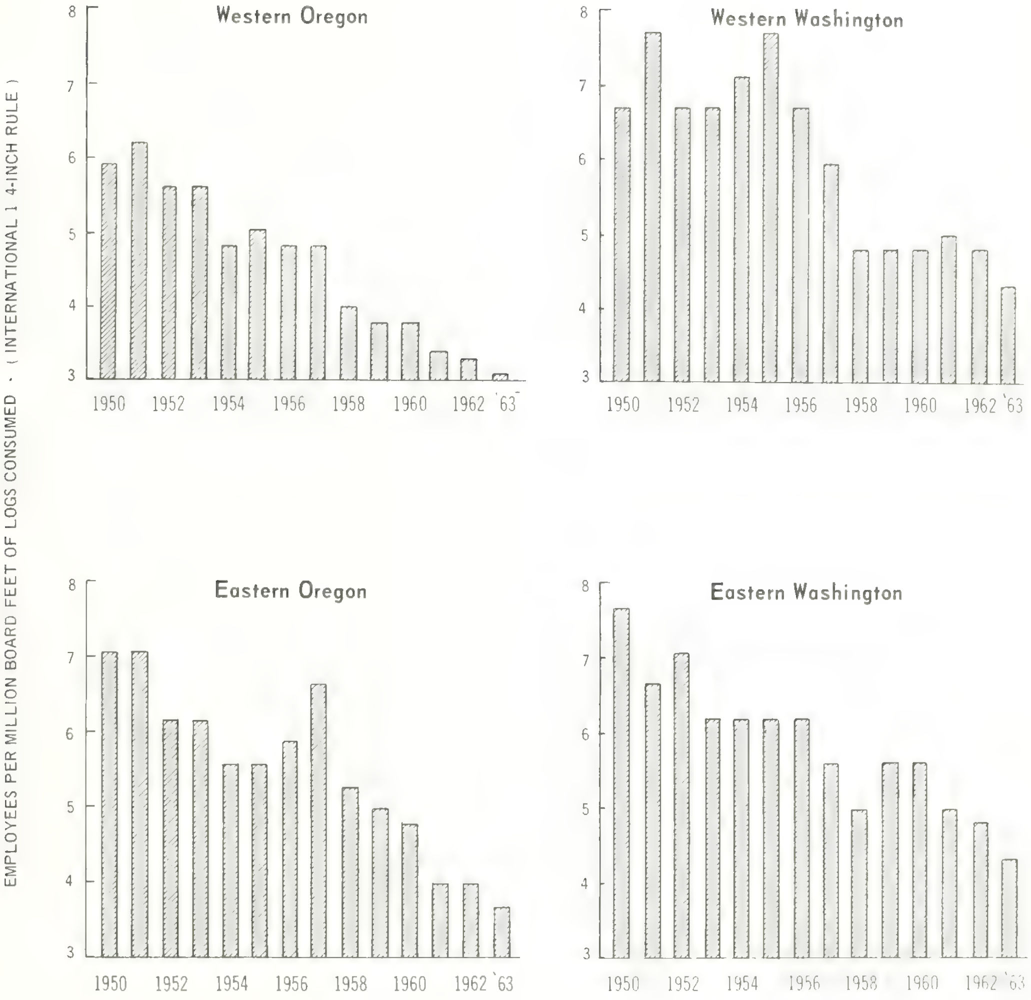

Figure 7.--Average annual employment in sawmills and planing mills per million board feet of logs consumed in Oregon and Washington, by State subregion, 1950-63.

Manpower Use by Job Function

Million board feet of lumber produced annually by three to four employees

In the sawmill and planing mill group, about 40 percent of the manpower use was in the sawmill operation, from pond to green chain, for the three major size classes (table 6). Class A mills (8-hour capacity, 120,000+ feet board measure) required 1.22 man-years per million feet of lumber output; class B (8-hour capacity, 80,000 to 119,000 feet), 1.46 man-years; and class C mills (8-hour capacity, 40,000 to 79,000 feet), 1.70 man-years per million feet. The larger mills probably used less labor because of more complete mechanization and faster operating speeds.

Table 6.--Man-years of employment in sawmills and planing mills per million board feet of lumber output, by job function and mill-size classes, in Oregon and Washington, 1962

Job function	Mill-size class[1/]					
	A (120+)		B (80-119)		C (40-79)	
	Number	Percent	Number	Percent	Number	Percent
Sawmill operation[2/]	1.22	38	1.46	45	1.70	42
Kiln-drying	.33	10	.37	11	.23	6
Planing mill	.66	20	.53	16	.87	22
Yards, sheds[3/]	.54	16	.44	14	.61	15
Other employees[4/]	.52	16	.47	14	.60	15
Total, dry surfaced lumber	3.27	100	3.27	100	4.01	100
Remanufacturing, other processing	7.89		8.86		8.28	

Source: Data supplied by 56 firms that produced 2,294 million board feet of lumber.

[1/] Thousand-board-foot capacity per 8 hours.

[2/] Pond through sawmill and green chain.

[3/] Includes shipping, yard transportation, fire protection, and power plant.

[4/] Primarily supervision, office, and unassigned maintenance.

The manpower use for kiln-drying differed for mills of different size classes but required only a small amount of labor in any mill, one-third of a man-year per million feet of lumber dried. Other job functions required approximately the same proportion of the total labor requirement in each mill-size class.

Total manpower for manufacturing dry surfaced lumber was 3.27 man-years per million feet for both A and B mills. In C mills, 4.01 man-years per million feet were used. Statistics for the smaller D mills (8-hour capacity, up to 39,000 feet) are not given because of wide variation among firms observed.

Remanufacturing and further processing, other than drying and planing, converts lumber into various kinds of cut stock and finished products and thereby adds about eight men per million feet of annual output--more than twice the labor needed for making dry, surfaced lumber.

Average manpower used for the sawmill operation (pond through sawmill and green chain) was generally lower in east-side mills than in west-side mills (table 7). Although the difference was very slight between B mills, differences of 0.26 man in A mills and 0.21 man in C mills for west side versus east side are apparently significant.

Table 7.--Sawmill manpower use, in employees per million board feet of annual lumber output, by selected mill-size class in Oregon and Washington and by subregion, 1962

Mill-size class[1]	West side[2]	East side[3]
	Number of employees	
A (120+)	1.28	1.02
B (80-119)	1.47	1.44
C (40-79)	1.83	1.62

Source: Data supplied by 56 firms that produced 2,294 million board feet of lumber.

[1] Thousand-board-foot capacity per 8 hours.

[2] West of Cascade Range.

[3] East of Cascade Range.

Output per man-hour

Average output of lumber per man-hour in sawmills and planing mills by mill-size class is shown in table 8. In the sawmill operation, output per man-hour was greater in large mills. The high kiln-drying output per man-hour is due to the small amount of labor involved--time, heat, and machinery do the work. Output per man-hour of all employees was 156 and 151 board feet in A and B mills, respectively, and was 128 board feet in C mills.

Sawmilling output per man-hour has increased steadily

Trends in output per man-hour for sawmills and planing mill firms that reported to the Western Wood Products Association are essentially parallel (fig. 8). West-side mills increased from 115 board feet per man-hour in 1950 to 145 board feet in 1962. Output per man-hour in mills on the east side averaged about 10 board feet per man-hour less during the same period.

Table 8.--Output of lumber per man-hour by operation, for sawmills and planing mills in Oregon and Washington, 1962

Operation	Mill-size class[1]		
	A (120+)	B (80-119)	C (40-79)
	Board feet		
Sawmill[2]	417	350	300
Kiln-drying	1,558	1,367	2,209
Planing	743	961	588
Yards and sheds[3]	952	1,158	833
All processes[4]	156	151	128
Remanufacturing, other processing	65	58	62

Source: Data supplied by 56 firms that produced 2,294 million board feet of lumber.

[1] Thousand-board-foot capacity per 8 hours.

[2] Pond through sawmill and green chain.

[3] Includes shipping, yard transportation, fire protection, and power plant.

[4] Weighted average, including supervision, office, and unassigned maintenance.

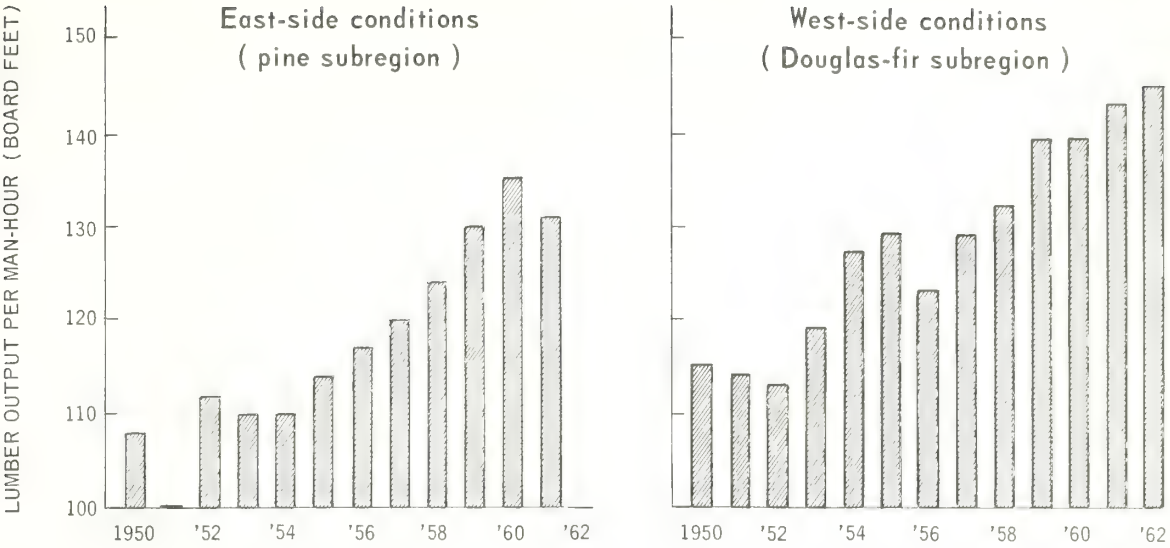

Figure 8.--Average lumber output per man-hour in sawmills and planing mills reporting to Western Wood Products Association, by subregion, 1950-62.

In the Pacific Northwest, the proportion of sawmill production workers to all sawmill employees was 90 percent in 1958.[5] Thus, these output data are higher than if all employees were included.

EMPLOYMENT IN THE VENEER AND PLYWOOD INDUSTRY

Plywood Employment Up 75 Percent

Oregon gain greatest

Veneer and plywood employment increased by 80 percent, from 18,300 workers in 1950 to 33,000 in 1963 (fig. 2). Oregon plywood employment increased sharply and steadily from 7,000 to 24,000 but, in Washington, employment dropped from 11,300 to 9,000 (fig. 9). Plywood production increased at a much greater rate[6] than employment, going from 2.4 billion square feet,

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[5] U.S. Bureau of the Census. 1958 census of manufactures. 1961.

[6] Production data in Oregon from U.S. Bureau of Census, "Current Industrial Reports, Softwood Plywood and Veneer, 1959-1962," and "Census Facts for Industry, Softwood Plywood and Veneer, 1953, 1955-58, Softwood Plywood 1950-53." For Washington, American Plywood Association figures were used because Census data include Idaho and Montana with Washington production.

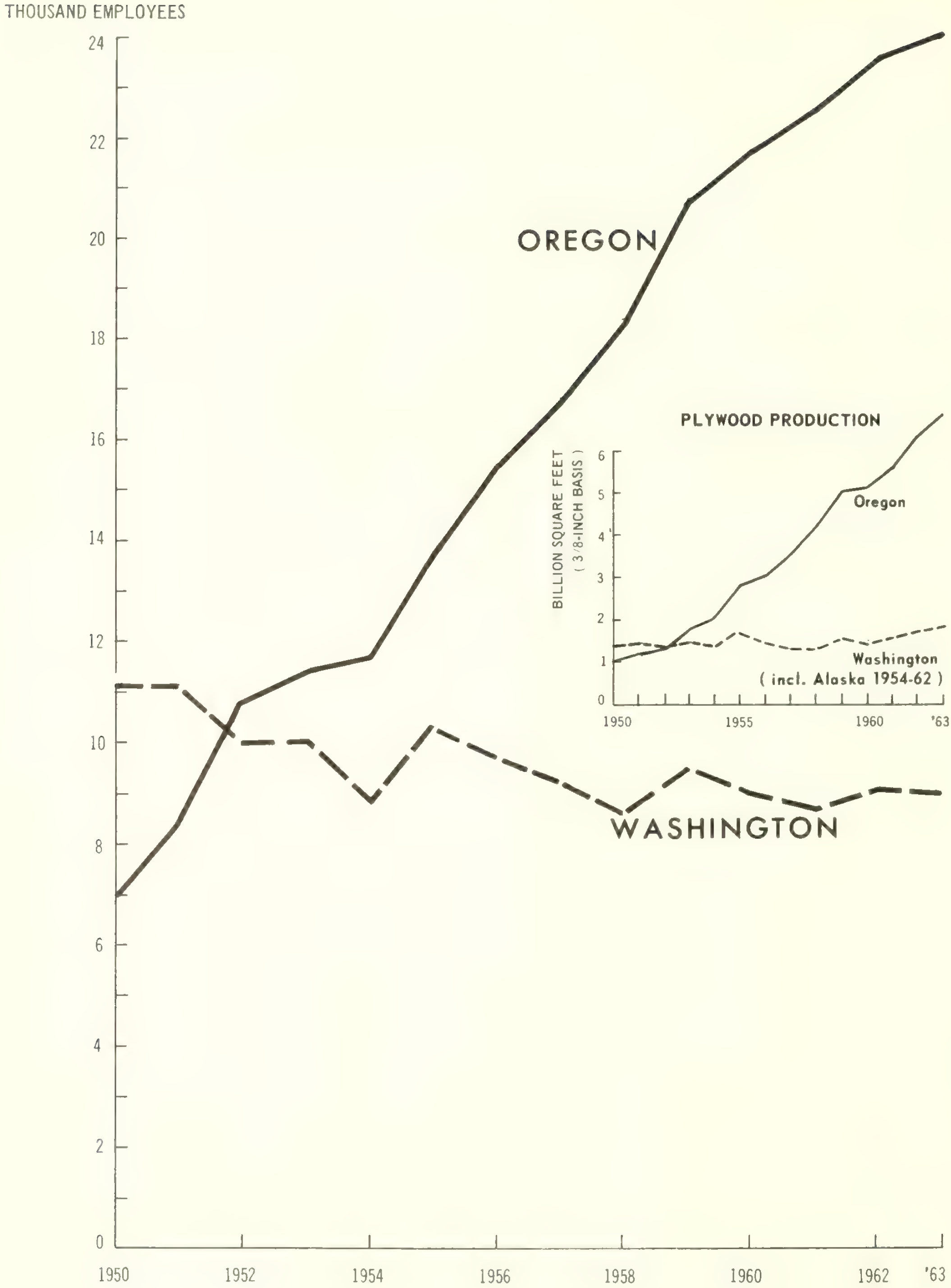

Figure 9.--Average annual employment and plywood production in veneer and plywood plants in Oregon and Washington, 1950-63.

3/8-inch rough basis, in 1950 to 8.6 billion square feet in 1963, an increase of 260 percent. In 1950, slightly more than 1 billion square feet of plywood were produced in Oregon and 1.3 billion in Washington. Mill capacity expanded rapidly in western Oregon, and by 1963, Oregon mills produced 6.8 billion square feet, and Washington had increased production slightly to 1.8 billion square feet. During this 14-year period, veneer and plywood employment in Oregon increased 240 percent but production increased by 530 percent; in Washington, employment dropped 20 percent although production increased 36 percent. Primarily, these changes reflect the movement of the plywood industries south from Washington and their rapid expansion in southwestern Oregon.

Manpower use in veneer and plywood plants down sharply

Veneer and plywood plants use approximately twice as much labor per unit of wood input as sawmills. Washington plants employed 16.7 workers per million board feet of logs used annually in 1950; by 1963, the manpower needs per million feet of logs used had dropped sharply to 9.8 workers (fig. 10).

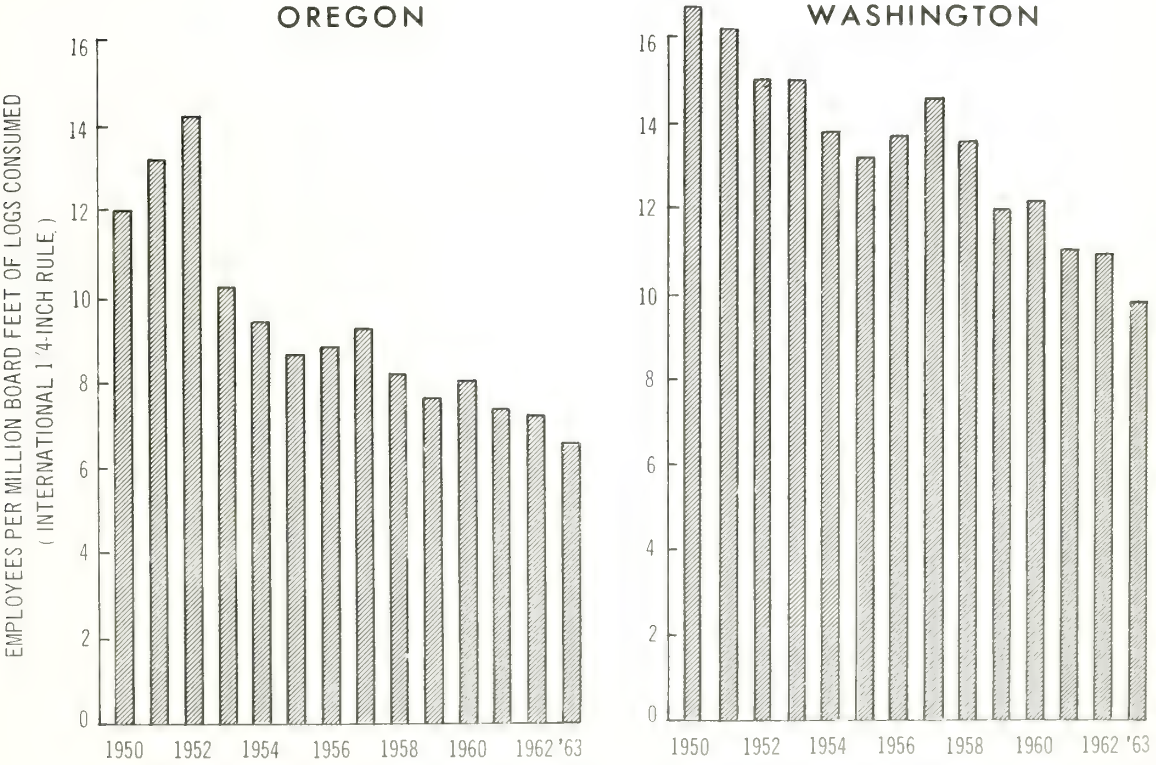

Figure 10.--Average annual employment per million board feet of logs consumed in veneer and plywood plants in Oregon and Washington, 1950-63.

Oregon veneer and plywood firms required 12.0 workers in 1950; by 1963 only 6.7 employees were needed.

Plywood output increasing at rate of 10 square feet per man-hour per year

Information supplied by the American Plywood Association was used to determine trends in output per man-hour in plywood plants. Data, reported to the association each month by plywood firms, were averaged for the years 1955 to 1962 and were weighted by quantity produced. Only firms that produced all veneer needed and sold none were included. The proportion of total production in sheathing varied among individual plants, but the average proportion in all plants sampled in a single year was between 26 and 40 percent and averaged 35 percent. A straight line fitted to annual averages (fig. 11) indicates that output per man-hour increased from 96 square feet, 3/8-inch rough, in 1955 to 166 square feet in 1962. The average annual increase was 10.07 square feet per man-hour. These rates are based on production workers only. According to the 1958 Census of Manufactures, this includes only 92 percent of all employees. Thus, the rates are higher than if the ratios included all employees.

The proportion of sheathing in total output influenced production rates markedly in selected years (fig. 12). In plants that produced sheathing exclusively, output per man-hour in 1956 was 50 percent greater than in plants that produced all sanded grades of plywood; in 1959 it was 32 percent greater. By 1962, significant changes in the rate of production of sheathing had taken place--output per man-hour was 228 square feet, or 69 percent more than in plants that produced no sheathing.

Manpower Use by Job Function

Output of veneer and plywood per man-hour during 1962 in 11 plants was:

Job function	Square feet, 3/8-inch rough basis
Veneer	815
Plywood (layup, etc.)	226
Integrated plant employees (all)	151

Plywood manufacture, with more employees handling each sheet, has a low output per man-hour compared with veneer. In an integrated plywood plant, production per man-hour, including nonproduction employees, drops to 151 square feet.

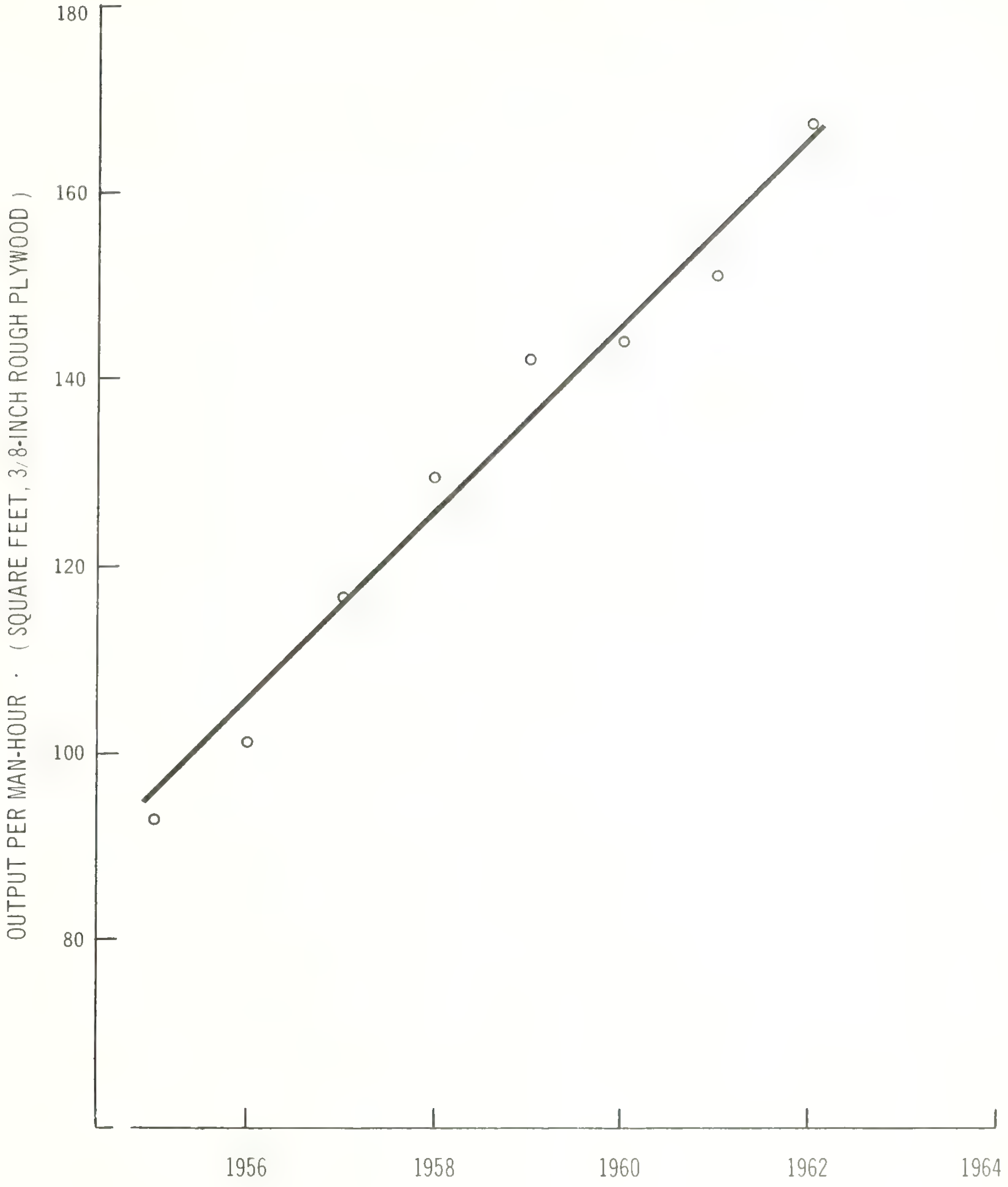

Figure 11.--Output of plywood per man-hour of plants that produced all veneer needed and sold none, as reported to American Plywood Association, 1955-62.

In integrated plywood plants that peel green veneer and also manufacture their own plywood from this green veneer, almost two-thirds of the employees were engaged in some phase of plywood manufacture--laying-up, pressing, trimming, patching, and sanding (table 9). Only 21 percent of the workers were engaged in peeling and drying veneer. In the plants sampled, one-third of the output was sheathing.

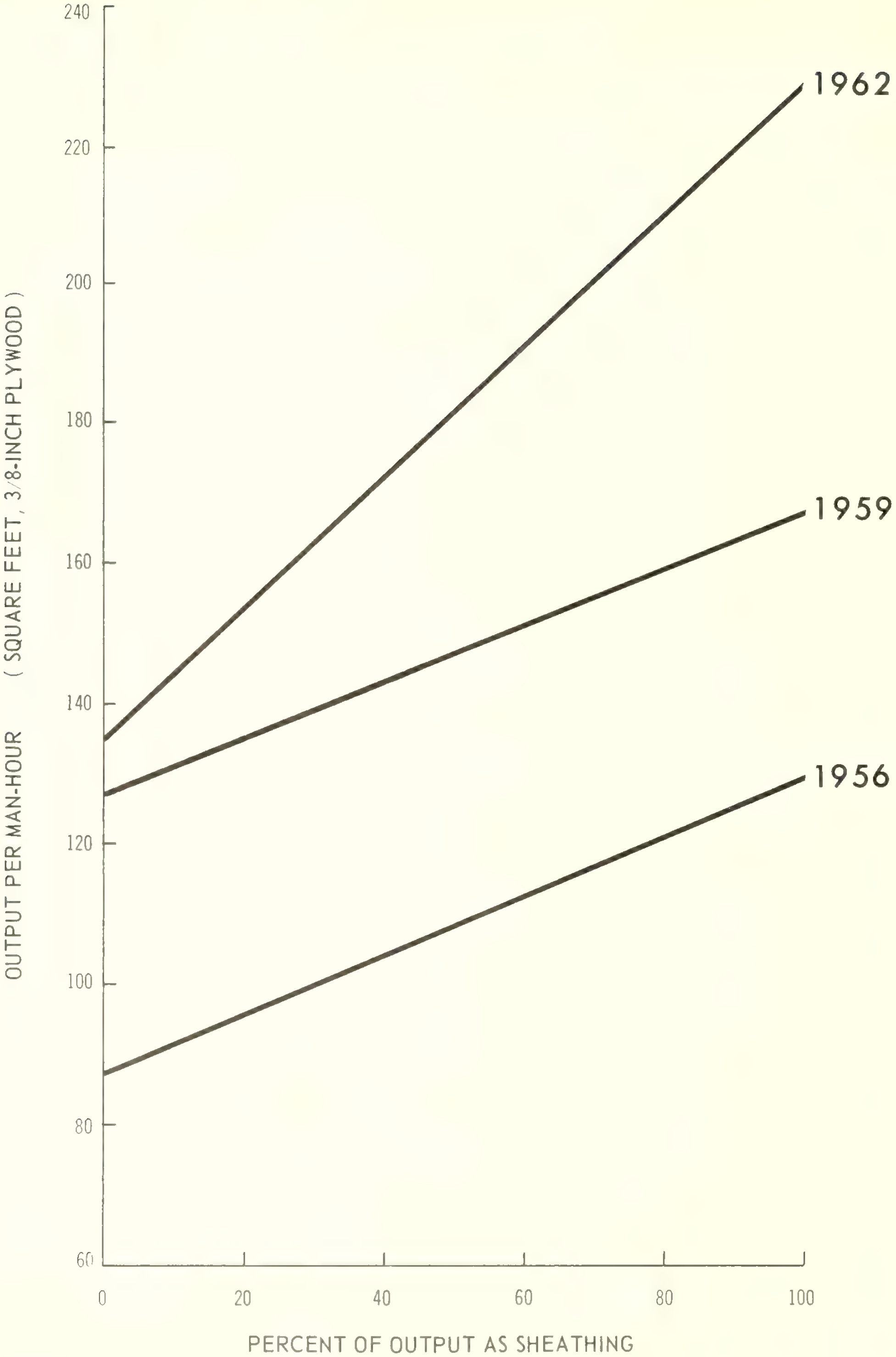

Figure 12.--Output of plywood per man-hour for selected years, by percent of total output in unsanded sheathing; plants that produced all veneer needed and sold none, as reported by the American Plywood Association.

Table 9.--Plywood plant manpower use by job function; number of employees per million feet of logs used annually in Oregon and Washington, 1962

Job function	Number of employees	Percent
Veneer	1.71	21
Plywood	5.21	65
Other	1.17	14
Total	8.09	100

Source: Data supplied by 11 plants that produced 518 million square feet of plywood, rough 3/8-inch basis.

EMPLOYMENT IN THE PULP AND PAPER INDUSTRY

Employment Trend Shows Steady Gain

Pulp and paper workers up 34 percent in 14 years

Employment in paper and allied products increased about 34 percent from 19,600 in 1950 to 26,200 persons in 1963 (fig. 2). Oregon increased its number of pulp and paper workers from 5,500 to 7,400 by the addition of new plants and by expansion of existing ones. Meanwhile, 4,700 workers were added in Washington to bring its total employment to 18,800 persons in 1963 (fig. 13). During this period (1962 was the last year the production data were available) pulp output increased steadily in both States from 2.4 million tons to 4.6 million and Washington pulpmills[7] consistently produced about 75 percent of this pulp.

Mills manufacturing paper, paperboard, and building paper show largest gain

Figure 14 shows that the largest part of the increase in employment in paper and allied products took place in mills that manufacture paper, paperboard, and building paper. Increased paper output is primarily responsible, but part of

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[7] Based on census data. Production figures for Washington include Alaska since 1954.

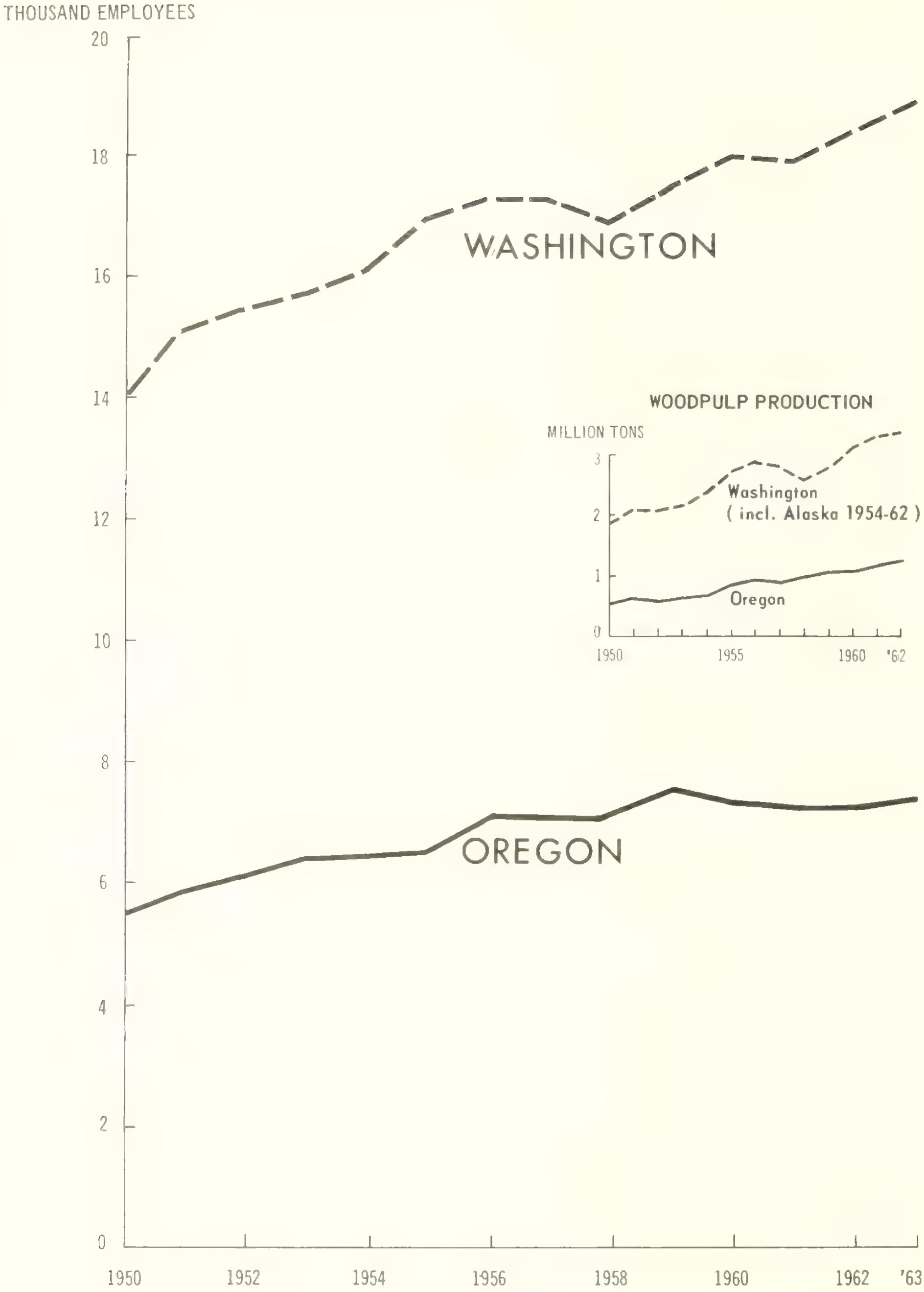
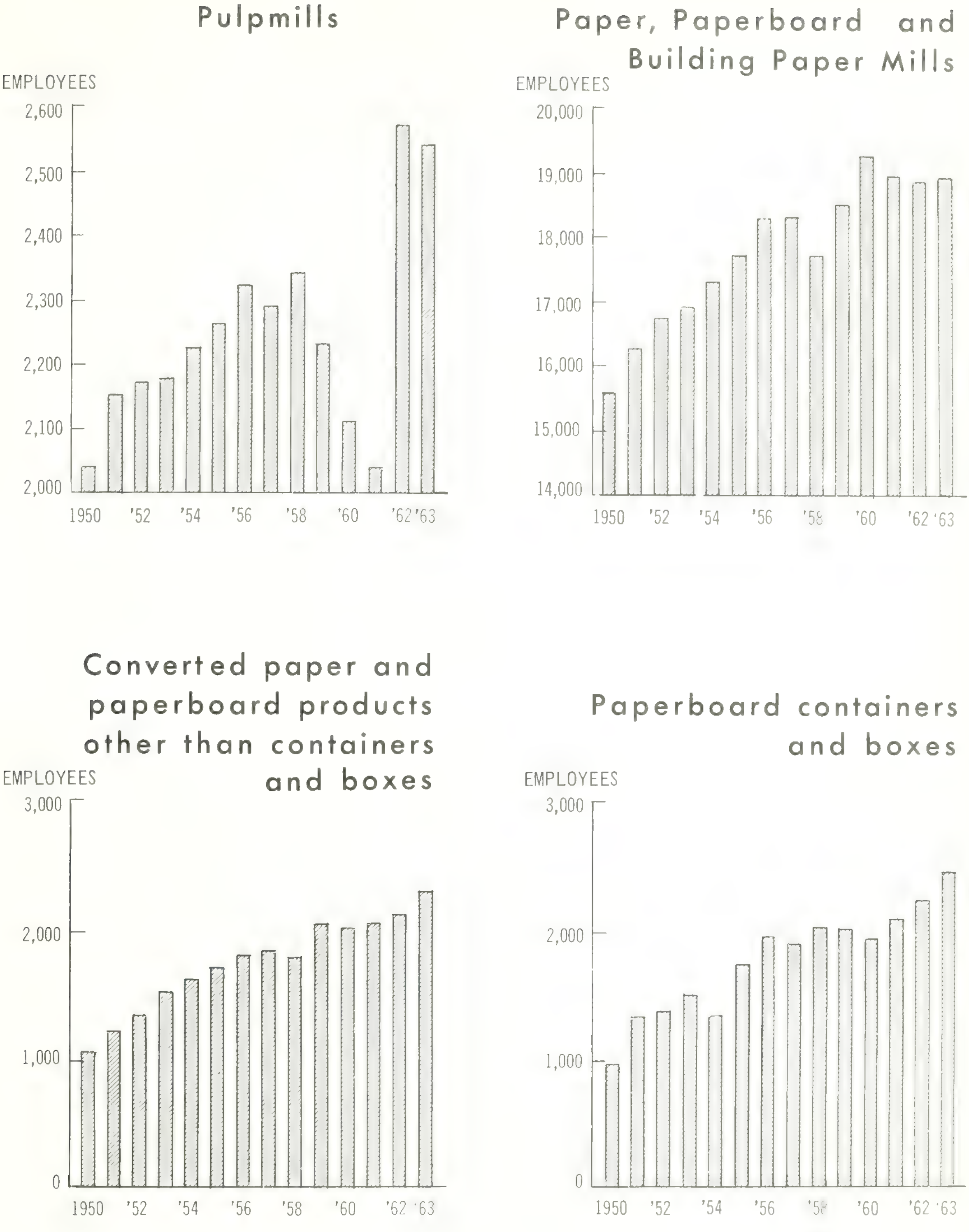


Figure 13.--Average annual employment and woodpulp production in the paper and allied products industries in Oregon and Washington, 1950-63.


Pulpmills

Paper, Paperboard and Building Paper Mills

Converted paper and paperboard products other than containers and boxes

Paperboard containers and boxes

Figure 14.--Average annual employment in the component industries of the pulp and paper industry in Oregon and Washington, 1950-63.

the increase may be due to the way the employment statistics are reported, as this industry classification includes some pulpmills combined with papermills and not separately reported.

A look at the composition of employment in the total paper and allied products field shows that almost 19,000 out of the total 26,200 employees in 1963 were working in the manufacture of paper, paperboard, and building paper (fig. 14). This is also the group showing the greatest increase in number of employees from 1950 to 1963. The number of workers in the other industries have all increased substantially, ranging from 24 percent gains in pulpmills to 156 percent in the manufacture of paperboard containers and boxes. Some caution is needed in interpreting figure 14 because the employment statistics for some mills producing paper and allied products, including pulp, do not differentiate as to exact nature of employment.

A compilation of capacity for pulp and papermaking in 1950 and 1962 (table 10) shows that pulp capacity doubled in both Oregon and in Washington. Paper capacity doubled in Washington and almost tripled in Oregon. Pulp capacity in Washington remained at 1.7 times that of paper. In Oregon, a 1950 pulp capacity of 1.3 times that of paper declined to 1.0 by 1962. Currently, pulp produced in Oregon is largely made into paper by mills within the State.

Table 10.--Production capacity of pulpmills and papermills in Oregon and Washington, 1950 and 1962[1]

Product	Capacity, 24 hours		
	1950	1962	Increase
			Percent
Oregon:			
Pulp (in tons)	1,836.00	3,796.00	107
Paper (in tons)	1,380.00	3,638.00	164
Ratio, pulp to paper	1.33	1.04	--
Washington:			
Pulp (in tons)	5,078.00	9,819.00	93
Paper (in tons)	2,877.00	5,725.00	99
Ratio, pulp to paper	1.76	1.72	--

[1] Lockwood's Directory of the Paper and Allied Trades, 75th and 87th editions.

Employment in industries that convert paper into paperboard containers and boxes and in industries that convert paper and paperboard products into other products more than doubled in 14 years (fig. 14). Most of the increase took place prior to 1956. These two classifications in the Standard Industrial Classification Manual[8] include all firms that buy paper and board for conversion into products, but do not include employees engaged in converting products at pulpmills and papermills.

Pulp and paper manpower use per cord declined more in Oregon

Annual manpower use in the pulp and paper industry in Oregon and Washington decreased during 1950-62 from 5.5 employees per thousand cords per year to 3.5. The decline in Oregon was steady, going from 7.8 employees per thousand cords in 1950 to 3.8 in 1962 (fig. 15). In Washington, a generally

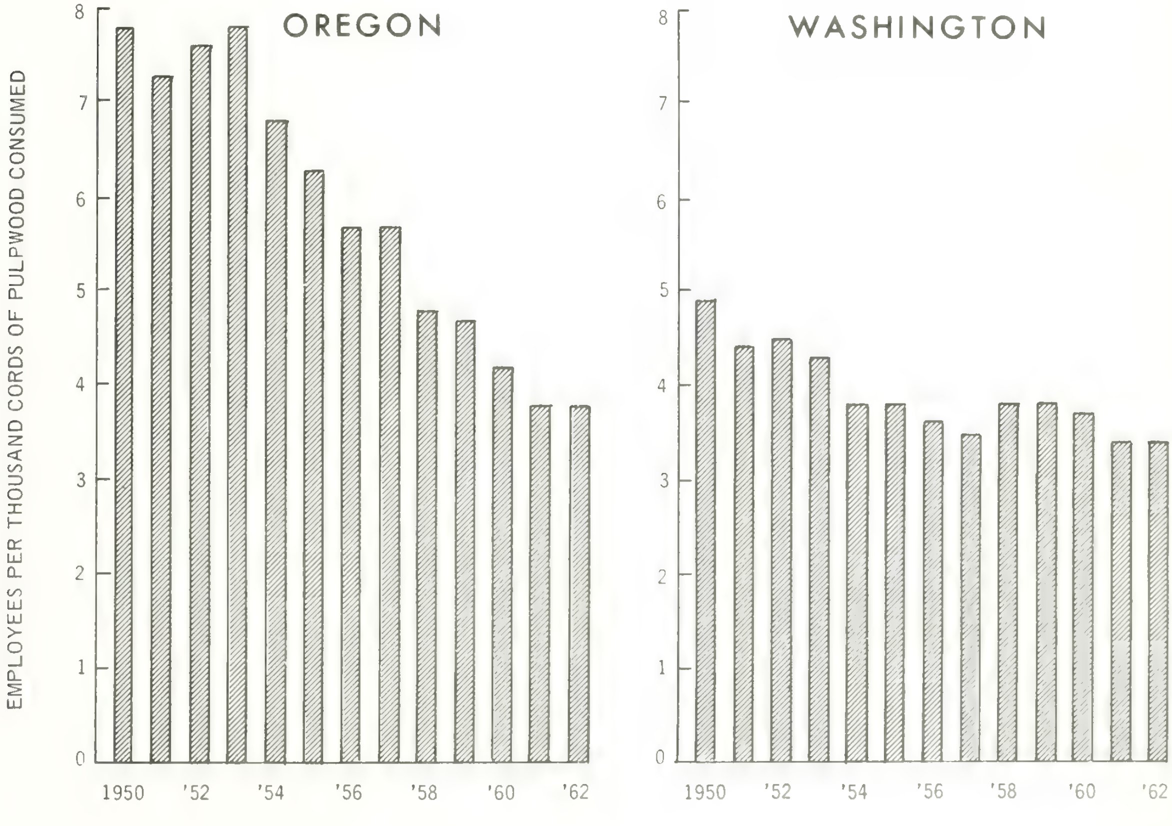


Figure 15.--Average annual employment per thousand cords of pulpwood consumed in paper and allied products in Oregon and Washington, 1950-62.

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[8] Prepared by the Technical Committee on Industrial Classification, Office of Statistical Standards, Bureau of the Budget, Executive Office of the President. 1957.

downward trend occurred between 1950 and 1957, but since then employment has been relatively level per unit of wood consumed. During the 13-year period, employment per thousand cords decreased 1.5, from 4.9 in 1950 to 3.4 in 1962. The number of employees per thousand cords of wood consumed approached 3.5 men in both States in 1962.

Manpower Use by Job Function

Data were collected from 15 pulp and paper plants that consumed 51 percent of all the pulpwood in 1962. The following is an estimate of the average number of employees per thousand cords of pulpwood used annually for various phases of the pulp and papermaking process:

Operation	Number of employees
Pulp:	
Production workers	0.84
Other employees	.23
All employees	1.07
Paper and paperboard:	
Production workers	1.31
Other employees	.35
All employees	1.66
Converted products:	
Production workers	3.65
Other employees	.97
All employees	4.62
Total, all operations	7.35

Less than one production worker was used per thousand cords of wood used to make pulp. Like many chemically oriented processes, pulping is highly mechanized, and a small number of employees can produce large quantities of pulp. Paper and paperboard manufacture needed an additional 1.66 men per thousand cords. The conversion of paper into products had a high labor need of 4.62 men--70 percent more than the manpower used for pulp and papermaking combined. Thus, employment in the Pacific Northwest pulp and paper industry at a given level of paper output is markedly influenced by the degree to which paper is converted to products in plants within the region.

Fifteen paper and allied products plants provided data from which output of production workers was computed. In pulping, 741 pounds of pulp were produced per man-hour. In paper and paperboard manufacture, 490 pounds were produced for each man-hour worked. Data on output of converted paper and board products were not available, but in terms of paper input to be converted to other paper products, average consumption of paper and board was 173 pounds per man-hour worked.

EMPLOYMENT IN OTHER WOOD-USING INDUSTRIES

Employment Shows Moderate Decline in 14 Years

Trends not well defined

Employment in other wood-using industries in Oregon and Washington decreased from 15,200 persons in 1950 to 14,300 in 1963 (figs. 2 and 16).

Although a comparison of employment at the start of the period with that of the end indicates some gains and losses, trends are not well defined. In general, it appears as if employment in this category, although somewhat variable, has stayed relatively constant.

Trends in employment in individual industries varied

In order to learn more about this composite group, the 1950-63 pattern of annual employment for individual industries within the group was determined (fig. 17). Although the record of employment is complete in Oregon, only since 1956 has Washington kept employment records by digit code, necessary for identification of each industry group. Consequently, the graphs making up figure 17 show Oregon trends from 1950 through 1955; then they are merged with those of Washington to show the common trend for two States. The only exception is the container industry where data is complete for both States over the entire time period.

Trends in employment are varied. Employment by firms that make prefabricated structures and parts shows a generally increasing trend. From 1956 through 1963, employment increased from 900 to 1,500 workers, reflecting the increasing acceptance and use of laminated-wood structural members, prefabricated wall sections, and other construction components. Another upward trend, at least in recent years, occurred in the special-product sawmills, which make alder furniture stock, cedar shingles, and small quantities of miscellaneous items. They are located in western Oregon and western Washington, with about three-quarters of the employment in Washington. Employment in this group increased from 2,600 in 1956 to 3,200 in 1963; much of this increase is attributed to an increased output of both furniture stock and cedar shingles.

A similar rise in employment has also occurred in the "miscellaneous" industry classification, with employment in recent years increasing from 1,300 in 1956 to almost 1,600 in 1963. Apparently the principal reason for this increased employment is the growth of the particle board industry which is included in this category.

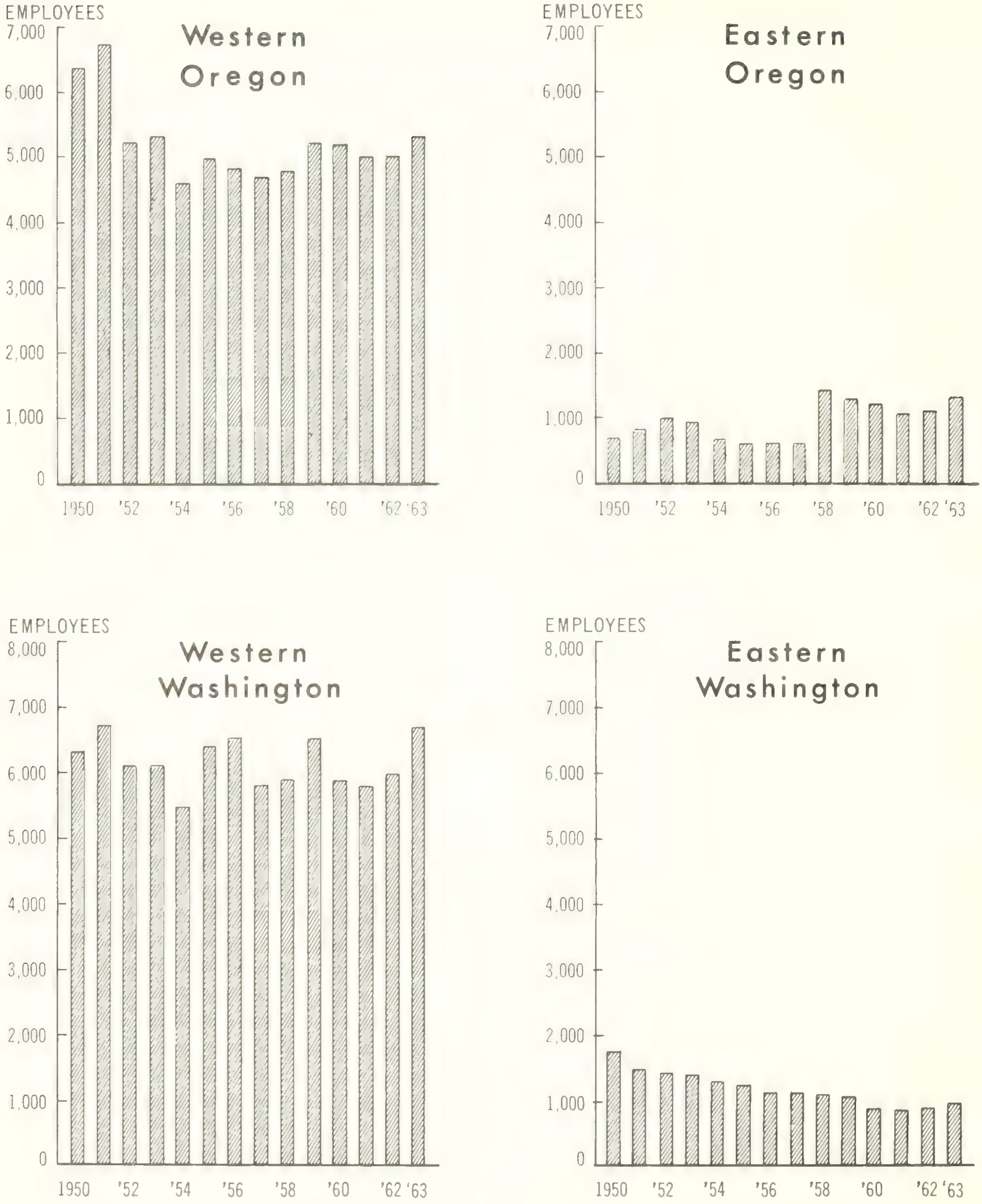

Figure 16.--Average annual employment in all other wood manufacturing in Oregon and Washington, by State subregion, 1950-63.

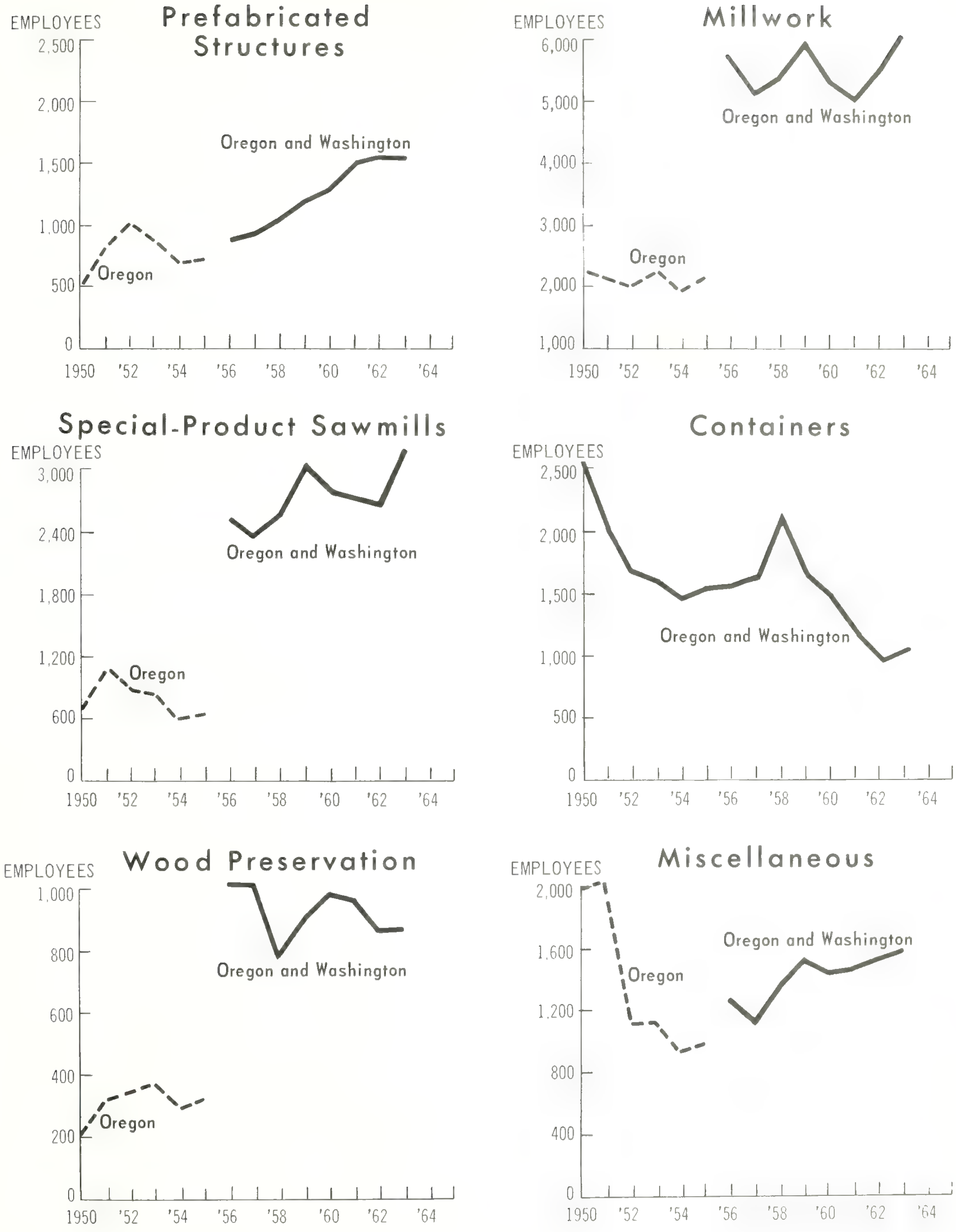

Figure 17.--Employment in component industries within all other wood-manufacturing groups in Oregon and in Washington, 1950-63.

Although 1963 employment in millwork reached a new high for the industry, past trends indicate an erratic pattern with no apparent long-term trend of either decreasing or increasing employment.

The continuous record of employment for the wood container industry indicates a gradual downward trend, from 2,600 in 1950 to 1,000 in 1963, due to competition from paperboard boxes and other containers. The large upswing in numbers of employees in 1958 may have been caused by several factors, but it is most likely associated with the reclassification of industries following revision of the Standard Industrial Classification in 1957. Employment in the wood preservation industry indicates a rather static situation without strongly observable trends. Employment between 1950 and 1956 in Oregon was about 300; the inclusion of Washington employment data in 1956 raised the total to about 1,000. Since 1956, the trend has been gradually downward, with 1963 employment being 870.

Man-use per unit of production for the "other" products industries was not determined because of the difficulty of obtaining adequate records of volume of output.

AVERAGE MONTHLY EMPLOYMENT IN OREGON AND WASHINGTON, 1957-61

Variation in Total Employment

Previously in this study, employment in the forest industries was reported as average annual number of workers. Employment in all forest industries fluctuates, more or less, during the year. For example, the seasonal nature of employment in logging is well known.

During the period 1948-53, employment in Oregon and Washington in lumber and other wood products combined varied from 15 percent below average employment to 10 percent above.[9] Seasonal variation in total employment in both States was substantially less, but was greater than that for total employment in the United States.

Statistics of employment by month in forest-based industries were analyzed for the period 1957-61 to determine monthly variation in employment as a percentage of average monthly employment during the 5-year period. All industry groups showed a somewhat similar seasonal pattern of employment, generally lowest during January, February, and March, and highest during

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[9] Mead, W. J. The forest products economy of the Pacific Northwest. Jour. Land Econ. 32(2): 127-133. May 1956.

July, August, and September. With the exception of converted paper products and preserved wood, most wood products are further processed by other manufacturers, used in commerce, or used in construction. Requirements for wood products fluctuate with the activity of these industrial purchasers. Thus, employment in the forest industries is strongly influenced by activity in other industries and trade.

Industries Differ Widely in Amount of Variation

Seasonal fluctuation large in logging industry

Logging employment varies substantially from summer to winter (fig. 18). In the monthly averages for the years 1957-61, August was the peak month in western Oregon, 22 percent above average monthly employment; but in western Washington, employment peaked earlier, reaching a high of 17 percent in June. Employment in both western Oregon and western Washington dropped to near average by November and reached a low point during January and February. Increased logging activity in the spring resulted in a return to average monthly employment by the end of April. In eastern Oregon and eastern Washington, seasonal fluctuation is more severe. In eastern Oregon, the range was from 24 percent above normal during August and September to 48 percent below in

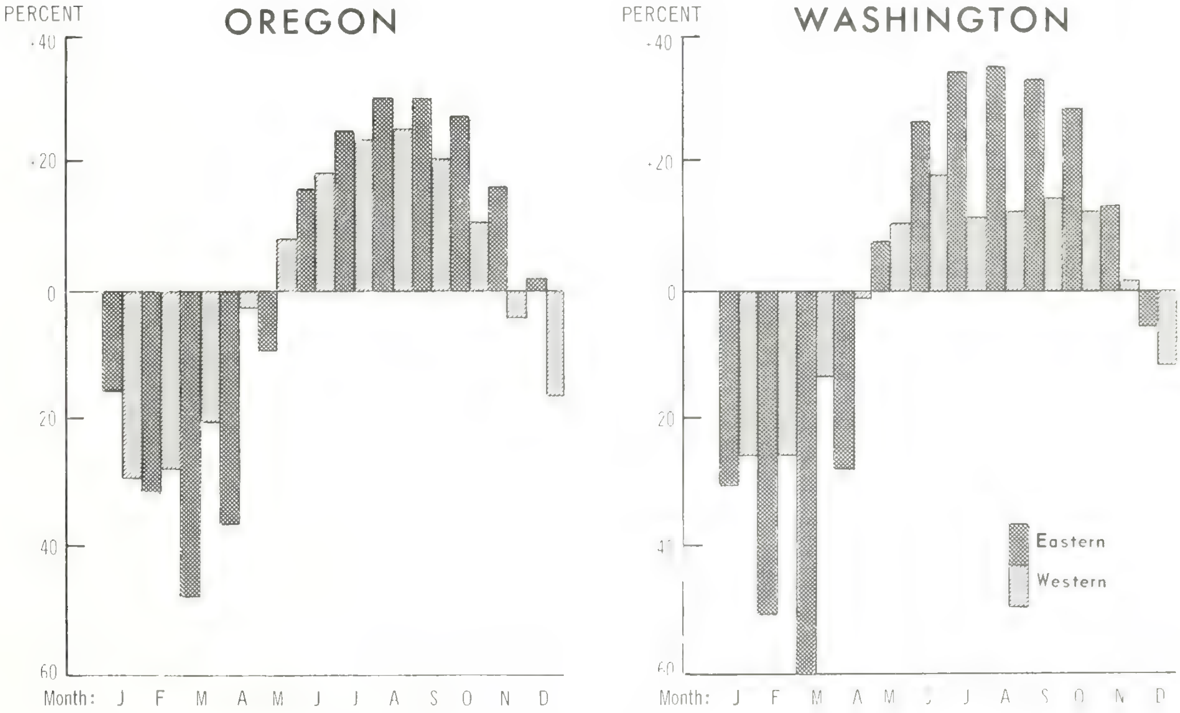


Figure 18.--Monthly deviations (in percent) from average logging employment during 1957-61 in Oregon and Washington, by State subregion.

March; in eastern Washington, the extremes were even greater, ranging from 35 percent above normal to 60 percent below. Logging activity apparently is more strongly influenced by unfavorable winter weather east of the Cascade Range. Logging employment showed a decidedly uniform cycle from summer to winter each year during the 5-year period.

Range of monthly sawmill employment ± 8 percent

Employment in sawmills and planing mills (excluding special products sawmills) shows less variation with almost identical seasonal patterns in Oregon and Washington. During the study period, the range in Oregon was from 8 percent above average in August to 8 percent below in January and February (fig. 19). In Washington these same months marked a 6 percent high and a 7 percent low in monthly employment. No differences were apparent between mills in eastern and western Oregon, but in eastern Washington the range in monthly employment was much larger from summer to winter than in western Washington.

The seasonal pattern of sawmill and planing mill employment is generally similar to that for logging. Lumber manufacturing is influenced both by log supply and seasonal requirements for lumber and other mill products. The Nation's construction industry, the largest consumer of lumber, is most active during summer months.

Less seasonal variation in plywood and paper industries

Employment in veneer and plywood plants shows the least variation in employment from month to month (fig. 20). Employment in the 5-year period

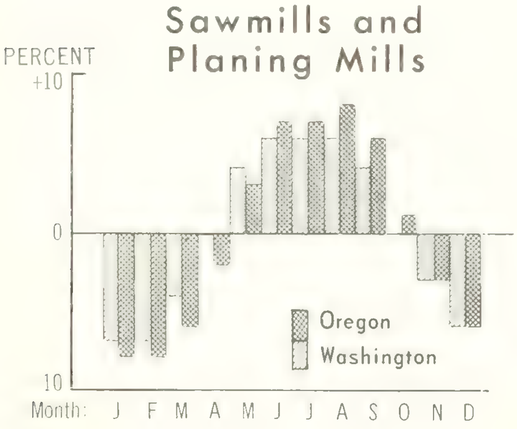


Figure 19.--Monthly deviations (in percent) from average employment during 1957-61 in sawmills and planing mills in Oregon and Washington.

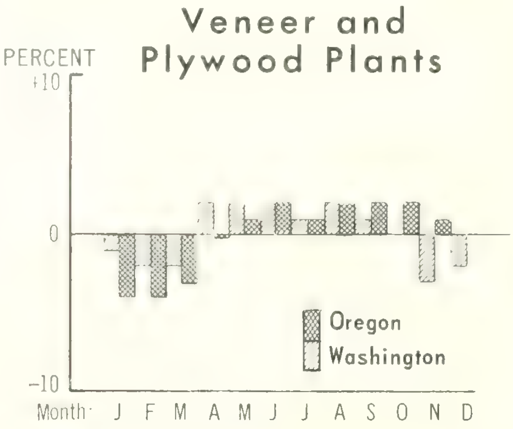


Figure 20.--Monthly deviations (in percent) from average employment during 1957-61 in veneer and plywood plants in Oregon and Washington.

ranged up to 2 percent above the annual average for 7 months of the year and dropped to only slightly less than average--3 percent in Oregon and 4 percent in Washington--during the off-season months. No regular cycle of monthly employment was apparent from year to year, although Oregon employment was highest in June in 4 out of 5 years.

Firms primarily engaged in making pulp, paper, and paperboard in Oregon experienced stability in employment comparable to that of the plywood industry (fig. 21). Employment varied from 4 percent above average in July to 2 or 3 percent below average from October through March. Peak summer months of employment were experienced each year.

Employment in building-paper mills in Oregon varied slightly more from summer to winter months (fig. 21), but regular yearly cycles were less evident. Only 1958 and 1961 showed pronounced gains in summer employment. Oregon paperboard container manufacturers experienced minor variation in employment from 4 to 5 percent above average in the summer to 3 to 6 percent below average employment from December through May. Each year had a uniform cycle which peaked in July and dropped to a low in January.

A similar analysis of the paper industries was not made for Washington. However, the nature of the industry would indicate relations generally comparable to those in Oregon.

Other industries show similar seasonal pattern but varying amount

Millwork employment was fairly stable, from 6 percent above average to 6 percent below average monthly employment (fig. 22). Here, as for the remaining "other" industries, the relatively small size of each industry group made it desirable to report variation in monthly employment for Oregon and Washington combined.

Employment in prefabricated structures and parts varied by 30 percent between August and February. This industry makes products on prior order, and it depends on seasonal construction activity. Millwork firms also supply the construction industry but rely less on custom work.

Wooden container manufacture was also highly seasonal, ranging from a high of 18 percent above average in July and August to a low of 16 percent below average in February. This was repeated in uniform cycles during the 5-year period.

Special product sawmills, primarily producers of alder furniture stock and wood shingles and shakes, exhibited a pattern of employment similar to general sawmills and planing mills during peak periods of employment. However, during the off-season period from January through March, employment in special product sawmills decreased more than in general sawmills.

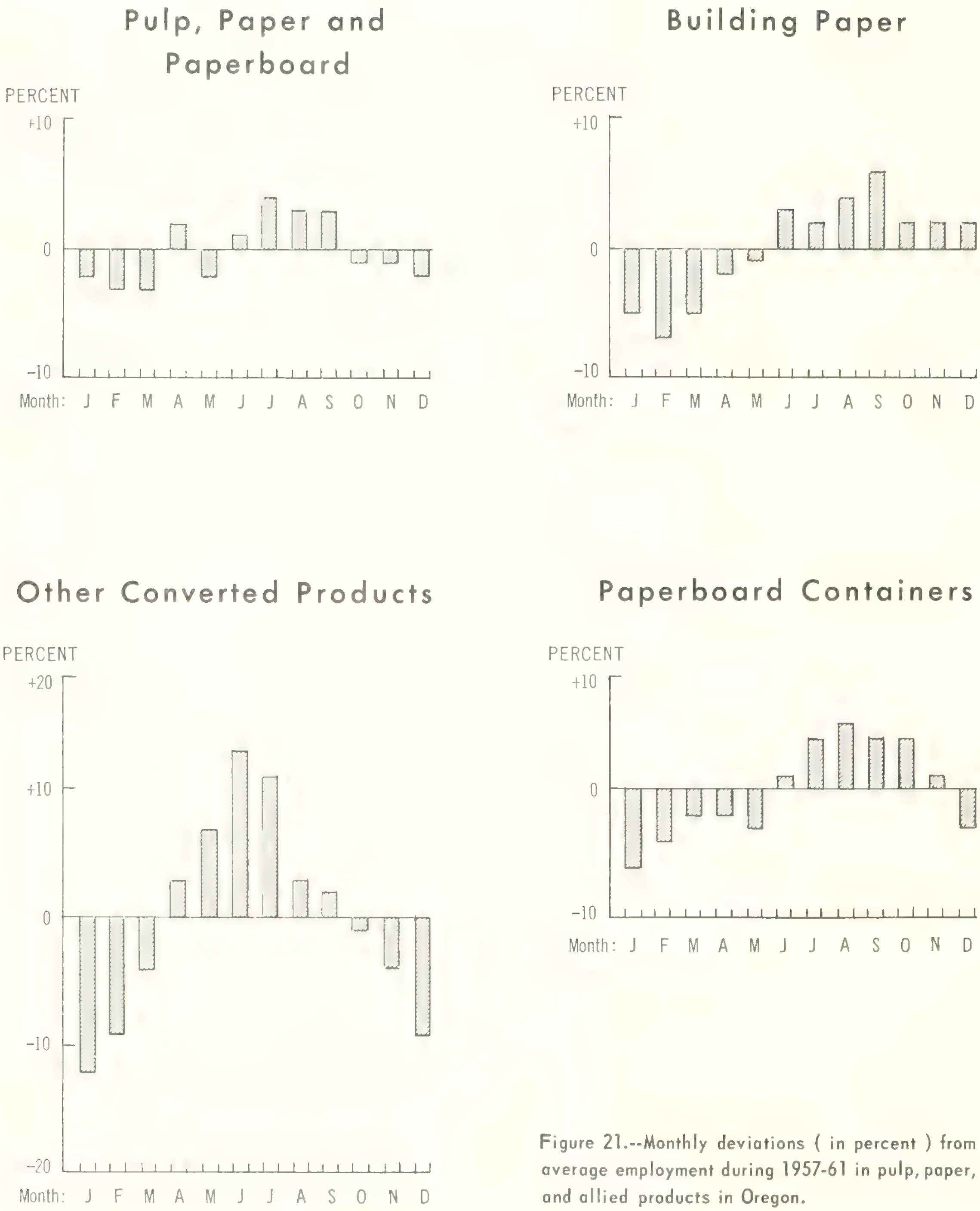
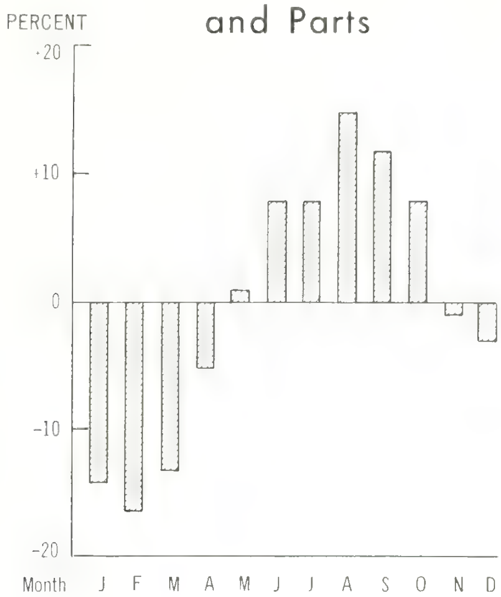
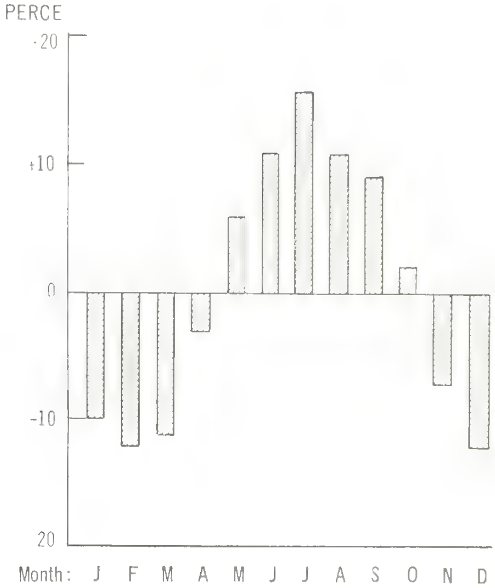


Figure 21.--Monthly deviations (in percent) from average employment during 1957-61 in pulp, paper, and allied products in Oregon.

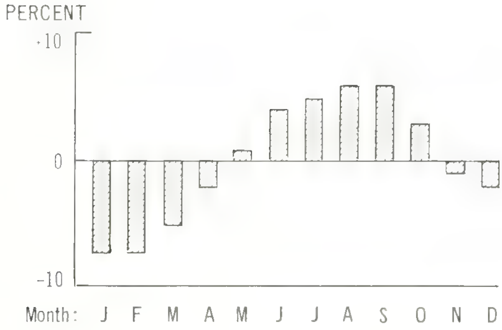
Prefabricated Structures and Parts



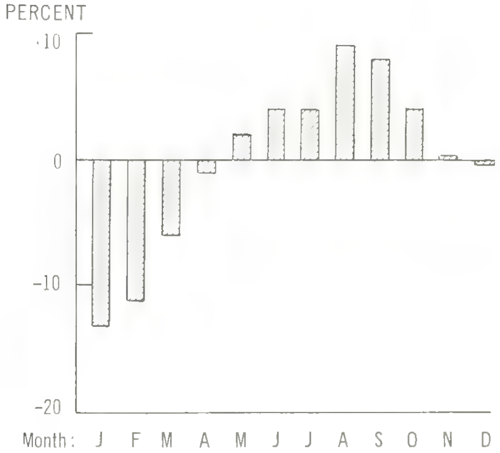
Wooden Containers



Millwork



Special-Product Sawmills



Wood Preservation

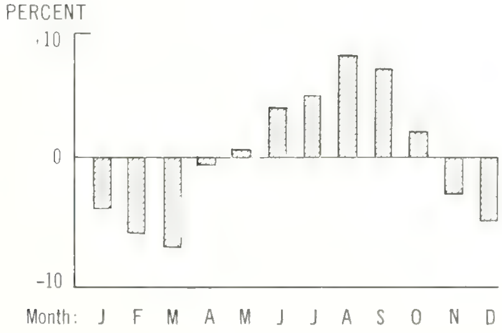


Figure 22.--Monthly deviations (in percent) from average employment during 1957-61 in other wood manufacturing in Oregon and Washington combined.

Employment in wood preservation, though cyclic from summer to winter, varied only 7 percent above and 8 percent below average employment.

Thus, with the exception of logging, prefabricated structures, wooden containers, and special product sawmills, employment in the wood-products industries, though exhibiting seasonal fluctuation, varied less than 10 percent from the annual average number of workers.

APPENDIX

Definition of Industries

Industries studied are included in "Major Group 24, Lumber and Wood Products, Except Furniture" and "Major Group 26, Paper and Allied Products," described in the "Standard Industrial Classification Manual." The major industries are:

Logging

Industry No. 2411. Logging camps and logging contractors.--Logging camps and logging contractors primarily engaged in cutting timber and in producing rough, round, hewn, or riven primary forest or wood raw materials. Independent contractors engaged in estimating or trucking timber, but who perform no cutting operations are classified in nonmanufacturing industries. Logging and woods operations conducted in combination with sawmills, pulp mills, or other converting establishments, and not separately reported, are classified in their respective industry groups; namely, with sawmills in Group 242, veneer and plywood mills in Group 243, pulp mills in Major Group 26, and charcoal and wood distillation plants in Group 286. Establishments primarily engaged in the collection of bark, sap, gum, and other forest byproducts are classified in nonmanufacturing industries.

Sawmills and Planing Mills

Industry No. 2421. Sawmills and planing mills, general.--Establishments primarily engaged in sawing rough lumber and timber from logs and bolts, or re-sawing cants and flitches into lumber, including box lumber and softwood cut stock; planing mills combined with sawmills; and separately operated planing mills which are engaged primarily in producing surfaced lumber and standard workings or patterns of lumber. This industry includes establishments primarily engaged in sawing lath and railroad ties, and in producing tobacco hogshead stock and snow fence lath. Establishments primarily engaged in manufacturing box shook or boxes are classified in Group 244; and sash, doors, wood molding, window and door frames, and other fabricated millwork in Industry 2431; and hardwood dimension and flooring in Industry 2426. Logging camps combined with sawmills, when not separately reported, are included in this Industry.

Veneer and Plywood Plants

Industry No. 2432. Veneer and plywood plants.--Establishments primarily engaged in producing commercial veneer, either face or technical, and those primarily engaged in manufacturing commercial plywood, including nonwood backed or faced veneer and nonwood faced plywood, from veneer produced in the same establishment or from purchased veneer.

Establishments primarily engaged in the production of veneer which is used in the same establishment for the manufacture of end products such as fruit and vegetable baskets are classified in Industry 2443, and wood boxes in Industries 2441 and 2442.

Other Wood Manufacturing

Industry No. 2426. Hardwood dimension and flooring mills.--Establishments primarily engaged in manufacturing hardwood dimension lumber and workings therefrom; and other hardwood dimension, semifabricated or ready for assembly; and hardwood flooring. Establishments primarily engaged in manufacturing stairwork, molding, and trim are classified in Industry 2431; and those manufacturing textile machinery bobbins, picker sticks and shuttles in Industry 3552.

Industry No. 2429. Special product sawmills, not elsewhere classified.--Mills primarily engaged in manufacturing excelsior, wood shingles, and cooperage stock, and in sawing special products, not elsewhere classified.

Industry No. 2431. Millwork plants.--Establishments primarily engaged in manufacturing fabricated millwork. Planing mills primarily engaged in producing millwork are included in this industry, but planing mills primarily producing standard workings or patterns of lumber are classified in Industry 2421.

Industry No. 2433. Prefabricated wooden buildings and structural members.--Establishments primarily engaged in manufacturing prefabricated wooden buildings, sections, and panels; or in producing laminated or fabricated trusses, arches, and other structural members of lumber. Prefabrication on the site of construction is not included in this industry.

Industry No. 2441. Nailed and lock corner wooden boxes and shook.--Establishments primarily engaged in manufacturing nailed and lock corner wooden boxes, and which also may produce shook for nailed and lock corner boxes.

Industry No. 2442. Wirebound boxes and crates.--Establishments primarily engaged in manufacturing wirebound boxes and crates.

Industry No. 2443. Veneer and plywood containers, except boxes and crates.--Establishments primarily engaged in manufacturing veneer and plywood containers, except boxes. This industry includes baskets made primarily of veneer and splint for shipping and marketing fruits and vegetables.

Industry No. 2445. Cooperage.--Establishments primarily engaged in manufacturing barrels, tubs, hogsheads, and other containers made of staves, except fruit and vegetable baskets (Industry 2443). Establishments primarily engaged in manufacturing tobacco hogshead stock are classified in Industry 2421, and those manufacturing cooperage stock in Industry 2429.

Industry No. 2491. Wood preserving.--Establishments primarily engaged in treating wood, sawed or planed in other establishments, with creosote or other preservatives to prevent decay and to protect against fire and insects. This industry also includes the cutting, treating, and selling of poles, posts, and piling, but establishments primarily engaged in manufacturing other wood products, which they may also treat with preservatives, are not included.

Industry No. 2499. Wood products, not elsewhere classified.--Establishments primarily engaged in turning and shaping wood, and manufacturing miscellaneous wood products, not elsewhere classified such as lasts and related products, cork products, mirror and picture frames, and particle board.

Pulp

Industry No. 2611. Pulp mills.--Establishments primarily engaged in manufacturing pulp from wood or from other materials such as rags, linters, waste paper, and straw. Logging camps operated by pulp mills, and not separately reported, are also included in this industry. Establishments primarily engaged in cutting pulpwood are classified in Industry 2411; and pulp mills combined with paper mills or paperboard mills, and not separately reported, are classified with the latter in Industries 2621 and 2631, respectively.

Paper, Paperboard, Building Paper and Board

Industry No. 2621. Paper mills, except building paper mills.--Establishments primarily engaged in manufacturing paper (except building paper-Industry 2661) from wood pulp and other fibers, and which may also manufacture converted paper products. Pulp mills combined with paper mills, and not separately reported, are also included in this industry; where separately reported, they are classified in Industry 2611. Establishments primarily engaged in manufacturing converted paper products from purchased paper stock are classified in Group 264 or 265.

Industry No. 2631. Paperboard mills.--Establishments primarily engaged in manufacturing paperboard, including paperboard coated on the paperboard machine, from wood pulp and other fibers; and which may also manufacture converted paperboard products. Pulp mills combined with paperboard mills, and not separately reported, are also included in this industry; where separately reported, they are classified in Industry 2611. Establishments primarily engaged in manufacturing converted paperboard products from purchased paperboard are classified in Group 264 or 265.

Industry No. 2661. Building paper and building board mills.--Establishments primarily engaged in manufacturing building paper and building board from wood pulp and other fibrous materials. Pulp mills combined with building paper and building board mills, and not separately reported, are also included in this industry; where separately reported, they are classified in Industry 2611.

Paperboard Containers and Boxes

Industry No. 2651. Folding paperboard boxes.--Establishments primarily engaged in manufacturing folding paperboard boxes from purchased paperboard.

Industry No. 2652. Set-up paperboard boxes.--Establishments primarily engaged in manufacturing set-up paperboard boxes from purchased paperboard.

Industry No. 2653. Corrugated and solid fiber boxes.--Establishments primarily engaged in manufacturing corrugated and solid fiber boxes and related products from purchased paperboard of fiber stock. Important products of this industry include corrugated and solid fiberboard boxes, pads, partitions, display items, pallets, single face products, and corrugated sheets.

Industry No. 2654. Sanitary food containers. Establishments primarily engaged in manufacturing food containers from special food board. Important products of this industry include fluid milk containers; folding paraffined cartons for butter, margarine, and shortening; ice cream containers; frozen food containers; liquid tight containers; round nested food containers; paper cups for hot or cold drinks; and pails for food and ice cream.

Industry No. 2655. Fiber cans, tubes, drums, and similar products.--Establishments primarily engaged in manufacturing fiber cans, cones, drums, and similar products with or without metal ends, from purchased materials; and vulcanized fiber boxes.

Other Paper and Board Products

Industry No. 2641. Paper coating and glazing.--Establishments primarily engaged in manufacturing coated, glazed, or varnished paper from purchased paper. Establishments primarily engaged in coating paper on the paper machine are classified in Industry 2621; those manufacturing carbon paper in Industry 3955, and photographic and blueprint paper in Industry 3861.

Industry No. 2642. Envelopes.--Establishments primarily engaged in manufacturing envelopes of any description from purchased paper and paperboard. Establishments primarily engaged in manufacturing papeteries (boxed stationery) are classified in Industry 2649.

Industry No. 2643. Bags, except textile bags.--Establishment primarily engaged in manufacturing bags from purchased paper, cellophane, acetate, polyethylene, pliofilm, foil, and similar sheet or film materials.

Industry No. 2644. Wallpaper.--Establishments primarily engaged in designing, printing, and embossing paper for interior walls, and ceilings. The paper stock used by this industry is called "hanging paper" and is produced by paper mills classified in Industry 2621.

Industry No. 2645. Die cut paper and paperboard; and cardboard.--Establishments primarily engaged in die cutting purchased paper and paperboard, and in manufacturing cardboard by laminating, lining, or surface coating paperboard. Establishments primarily engaged in laminating building paper or building board from purchased paper or board are classified in Industry 2649.

Industry No. 2646. Pressed and molded pulp goods.--Establishments primarily engaged in manufacturing all kinds of pressed and molded pulp goods, including papier-mache' articles other than statuary and art goods (Industry 3299). Establishments primarily engaged in manufacturing plates and utensils from paper are classified in Industry 2654.

Industry No. 2649. Converted paper and paperboard products, not elsewhere classified.--Establishments primarily engaged in manufacturing from purchased paper or paperboard miscellaneous converted paper or paperboard products, not elsewhere classified.

Other wood manufacturing

Several SIC divisions within Major Group 24 were combined as miscellaneous wood manufacturing when employment was reported. The group includes hardwood dimension mills, shingle mills, millwork plants, prefabricated structures, wooden containers, and wood preserving. Industries in this group are either secondary manufacturers or they process a small amount of the total log harvest. They employ a relatively small proportion of the total number of workers. Manpower requirements of these industries were not studied because of the difficulty in determining quantity of wood processed, the many different processes involved, and the lack of a satisfactory common unit of volume measurement.

Paper and allied products

Establishments primarily engaged in the manufacture of pulps from wood and other cellulose fibers and rags; the manufacture of paper and paperboard; and the manufacture of paper and paperboard into converted products such as paper coated off the paper machine, paper bags, paper boxes, and envelopes. Employment was reported for industries within the paper and allied products group.

Wood is consumed by firms in Major Group 25, Furniture and Fixtures, but these industries were not studied because the quantities of wood processed, often in combination with other materials, and numbers of workers employed in the Pacific Northwest are small.

Compilation of Employment Statistics

Employment in the forest industries for the period 1950 to 1963 was compiled as the annual average number of employees. Data furnished by the Oregon Department of Employment and Washington Employment Security Department were based on reports of average monthly employment and payrolls submitted by employers whose workers are entitled to benefits provided by State unemployment laws. The method of reporting, based on the payroll period which ends closest to the 15th of the month, may obscure fluctuations resulting from employment of part-time workers. Part-time employment chiefly affects the number of employees reported by small logging contractors. Employment in all wood-using industries is subject to more or less seasonal fluctuation. The use of annual averages tends to level seasonal fluctuation to the equivalent number of full-time workers employed during the year.

Employment statistics include all employees of a firm: production workers, maintenance and other plant workers, clerical, supervisory overhead, technical and staff workers, and company officials, but they do not include owners. The practice of reporting all employees in the main business of the firm distorts some of the classifications. A sawmill operator's report may combine both a logging crew and millworkers. The number of workers is classified under "2421, Sawmills and planing mills, general," because lumber manufacture is the main business of the firm. Similarly, employees of a pulp and paper manufacturer, including both workers in the pulpmill and those in the papermill, may be classified under "2621, Papermills, except building paper mills." Such combinations occur chiefly in the reports of small firms where the number of employees is few. Whenever possible, State agencies obtain separate reports of employment where more than one classification of workers is employed by a firm. The effect of such combinations, as used in this study, is minor. The Standard Industrial Classification was revised in 1957. Changes in the timber industries were accounted for or they did not materially affect classification in the industries as grouped for study.

In Washington, all employees in the manufacturing sector, regardless of size of firm or amount of payroll, have been covered by employment security legislation since before 1950. In Oregon, from 1950 to 1955, firms with less than four employees were not required to report, and from 1956 to 1959, firms with one employee did not report. No adjustments were made in the reported figures for lumber and wood-products employment, as firms employing less than four persons prior to 1956 or less than two prior to 1960 are not significant in the employment picture for this classification.[10/] Since 1960, coverage has been complete in the manufacturing sector.

Statistics on Volume of Wood Used by Forest Industries

Volume of logs harvested was taken from annual reports of log production, issued by the Forest Survey, Pacific Northwest Forest and Range Experiment Station, Portland, Oregon. This was converted from the reported Scribner log volume to International 1/4-inch volume by use of a factor of 1.25 on the west side and 1.10 on the east side of the Cascade Range.

Volume of logs used by sawmills was based on reports of annual lumber production by State, issued by the Bureau of the Census, U.S. Department of Commerce: "Facts for Industry," Series M24T (formerly M13G), and "Current Industrial Reports," Series M24T. Log volumes, when in terms of the International 1/4-inch rule, were considered the equivalent of lumber production. Lumber production was allocated to State subregion according to the percentage of total lumber production reported for the west side by the West Coast Lumbermen's Association Statistical Yearbook, 1959-62, and for the east side by Circular 483 of the former Western Pine Association.

Volume of logs consumed in making veneer and plywood in Oregon was obtained from the Bureau of the Census "Facts for Industry," Series M24H (formerly Series M13B), and, in recent years, from "Current Industrial Reports," Series M24H. Census data were not used for Washington as they include Idaho and Montana production. Instead, production data for Washington were from American Plywood Association. Production data were converted to Scribner log scale on the basis of an output of 2.4 square feet, 3/8-inch rough, per board foot of log consumed. Scribner volumes for logs were converted to International 1/4-inch volume as reported above.

Statistics of pulpwood consumption, contained in Bureau of the Census "Facts for Industry," Series M14A, and "Current Industrial Reports," Series M26A, were adjusted, using data from several sources. Adjustment was necessary to account for data withheld to prevent disclosure of information concerning individual firms and inclusion of pulpwood consumption for areas other than Oregon and Washington.

[10/] Trends of Employment in Oregon, 1950-1960. p. 111. Prepared for the Bonneville Power Administration by the Bureau of Business Research, University of Oregon, February 1962.

Trends in Output Per Man-Hour

The results of increasing labor efficiency, substitution of machines for hand labor, improved plant layout, organization of the labor force, and product specifications can be expressed as increased output per man-hour or as decreased manpower use per unit of wood input. Since the source of data or number of employees cannot be used to accurately determine number of hours worked and since number of employees includes nonproduction workers, other sources are needed to get measures of output per man-hour. The Western Wood Products Association (formerly, West Coast Lumbermen's Association and Western Pine Association) and the American Plywood Association (formerly, Douglas Fir Plywood Association) have the necessary data from mills reporting directly to them for the lumber and plywood industry. Similar data are not available for the pulp and paper industry. The association data for manpower use differ from those previously shown because they include production workers only. According to the Census of Manufactures in 1958, the proportion of production workers to all employees in the Pacific Northwest was:

Industry	Percent
Logging	89
Sawmills and planing mills	90
Veneer and plywood	92

Thus, output per man-hour, based on association data, is approximately 10 percent higher than if the ratios were based on all employees.

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NATIONAL FOREST SYSTEM
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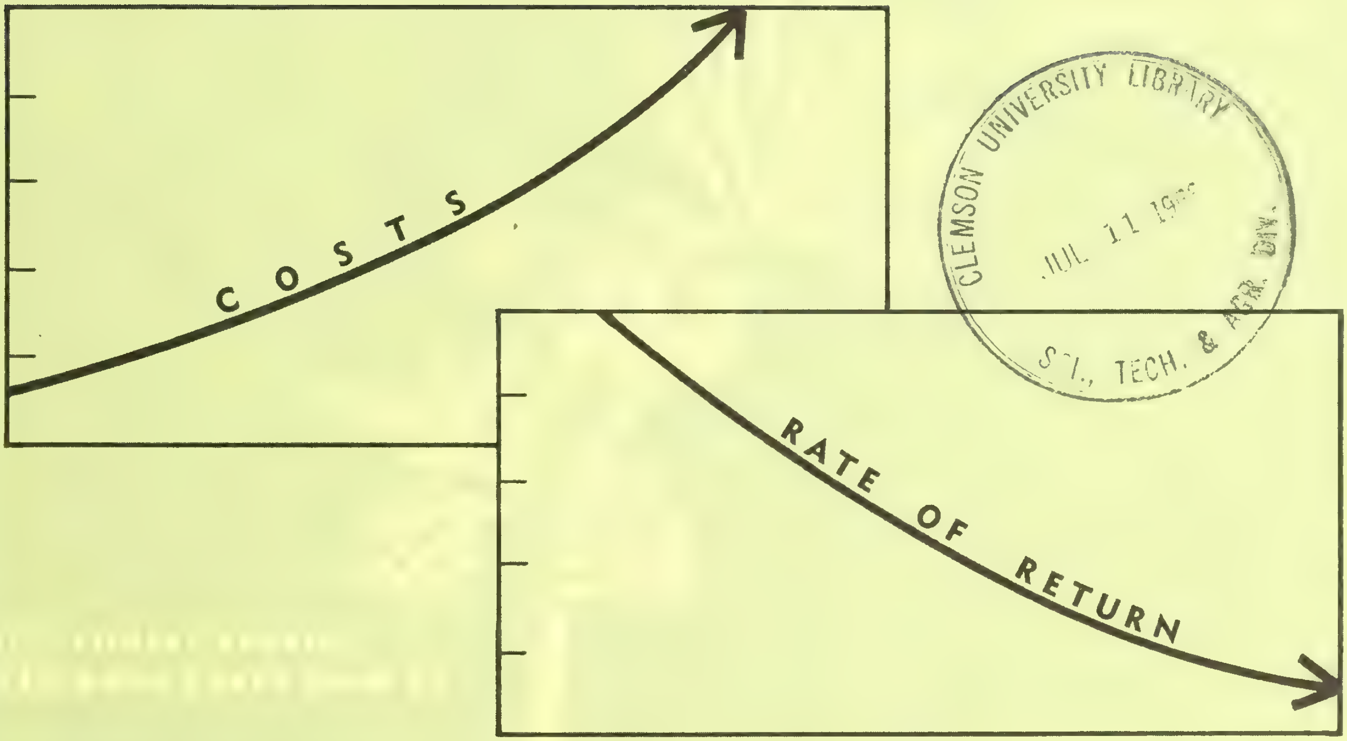

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PREFACE

The size of this publication is scarcely indicative of the research effort on which it is based. Many individuals throughout the West participated in the 5-year undertaking. At the Rocky Mountain Forest and Range Experiment Station, Stuart Andrews and Frank Hawksworth provided a substantial quantity of data from their continuing studies of dwarfmistletoe behavior and impact in the Southwest. T.W. Childs and James Edgren at the Pacific Northwest Forest and Range Experiment Station, assisted by Ray Yoder of Oregon State University, undertook research directed toward both provisional and definitive quantification of dwarfmistletoe impact on ponderosa pine in the Northwest. Floyd Johnson and Dorothy Martin advised on statistical, mathematical, and computational matters. George Meagher and Carl Berntsen were consulted about ponderosa pine silviculture.

Benton Howard, of U.S. Forest Service Region 6 Regional Office, and Barney Duberow, Deschutes National Forest, coordinated the extensive control cost studies. Donald Graham, Regional Office, and Kenneth Dykeman, James Simonson, and Robert Pederson, Deschutes National Forest, participated in planning and field supervision of the work.

The overall economic study was initiated by Carl Newport, Pacific Northwest Station; John Fedkiw, now with the U.S. Forest Service, Washington Office; and Robert McMahon, now at Yale University.

Although every effort has been made to incorporate the most recent information on ponderosa pine and dwarfmistletoe behavior, important advances in information and control philosophy are continuously underway. The high cost of present control methods considered, it is hoped that the guidelines presented here will in time be made obsolete by such advances.

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INTRODUCTION

Figure 1.--Ponderosa pine dwarfmistletoe.

This publication suggests economic guides--costs and rates of return--for selecting control areas and controlling ponderosa pine dwarfmistletoe (fig. 1). It is intended for the practicing forester in the Northwest who wants criteria for distributing a limited management budget among several management opportunities on many different stand types and site conditions.

The effects of mistletoes on their hosts have been observed for many years.[1] Dwarfmistletoe reduces vigor and causes large brooms and enlarged branches which, in turn, reduce wood production and seed quantity and viability and may eventually induce early mortality.

The species of ponderosa pine dwarfmistletoe involved in this report are *Arceuthobium vaginatum* and *A. campylopodum* (Engelm.) f. *campylopodum* (Gill 1954).

Dwarfmistletoe is apparently ubiquitous; it has been found in all parts of the range of ponderosa pine (Gill and Hawksworth 1961, *p.45*) except the Black Hills, although its intensity is highly variable. Studies of dwarfmistletoe intensity and its impact on ponderosa pine have encompassed only portions of the West. The most extensive survey was that of Andrews and Daniels (1960) on the National Forests and Indian Reservations of Arizona and New Mexico. Thirty-six percent of their ponderosa pine plots had some degree of infection, suggesting that 2.5 million acres of commercial ponderosa pine timberland are infected there. Hawksworth and Lusher

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[1] A comprehensive survey of literature on the entire mistletoe family (Loranthaceae) has been prepared by Gill and Hawksworth (1961). A cross section of American publications concerned with ponderosa pine might include Andrews (1957), Childs (1963), Gill (1954), Gill and Hawksworth (1954), Hawksworth (1961), Hawksworth and Lusher (1956), Herman (1961), Kimmey (1957), Korstian and Long (1922), Linnard (1961), Roth (1954), Wagener (1961), and Weir (1916). Names and dates in parentheses refer to Literature Cited, p. 17.

(1956) found that 53 percent, or 88,000 acres, of the ponderosa pine type on the Mescalero Reservation were infected. In the Northwest, Roth (1953) found patch-like infection of 32 acres on a 160-acre tract of typical virgin forest in eastern Oregon. Childs and Greene,[2] in a survey of part of the Deschutes National Forest in Oregon, found ponderosa pine dwarfmistletoe infection in small, scattered patches on 18 percent of their 3,128 stocked plots.

In southern California, "The disease is widely distributed and has built up locally to epidemic proportions"; and a statewide survey revealed that dwarfmistletoe was present on 30 percent of plots in the ponderosa pine type (U.S. Forest Service 1960, *pp. 42-47*).

Without question, the spread of dwarfmistletoe, a seed-bearing parasite, can be controlled. Apparently, lateral spread of the plant through even-aged stands is not more than about 2 feet per year (Hawksworth 1961, Roth[3]). Where overstory trees allow dwarfmistletoe seed to fall on an understory, the maximum range of overhead dispersal is about 130 feet (Roth 1953). It appears that birds and rodents are not important local transporters of dwarfmistletoe seed (Hawksworth 1961, *p.66*). Thus, control can be achieved by removing or pruning infected trees.

Knowledge about the productivity of infected stands under different stocking, tree size, and infection conditions is limited. Indeed, little is known about the growth of partially stocked ponderosa pine stands such as would result from removal of infected trees. Further, many factors affect the economic feasibility of dwarfmistletoe control. To deal with the complex relationships, a number of assumptions and mathematical equations have been employed. Some are indicated in the text; others are explained in a forthcoming report which also explains the data used.[4]

METHODS OF CONTROL

Control of dwarfmistletoe requires removing infected branches or, where the parasite has become established on the trunk of a tree, felling the entire tree. Because the endophytic system of the dwarfmistletoe plant within the branch of a host tree may extend ahead of visible shoots, it is necessary to assume that dwarfmistletoe branch infections, visible close to the trunk of a tree, have already invaded the stem.[5]

[2] Childs, T.W., and Greene, W.B. Dwarfmistletoe surveys on the Deschutes National Forest, 1958. 34 pp. 1959. (Unpublished report on file at Pacific NW. Forest & Range Expt. Sta., U.S. Forest Serv., Portland, Oreg.)

[3] Roth, L.F. Observations of pine dwarfmistletoe, Pringle Falls Experimental Forest, July 7 to August 8, 1952. 1952. (Unpublished report on file at Pacific NW. Forest & Range Expt. Sta., U.S. Forest Serv., Portland, Oreg.)

[4] Flora, Donald F. Forecasting returns from ponderosa pine dwarfmistletoe control. (In preparation for publication, Pacific NW. Forest & Range Expt. Sta., U.S. Forest Serv., Portland, Oreg.)

[5] Hawksworth and Andrews (1961) suggest the following rule for pruning infected branches: "Branches 1.0 inch or less in diameter may be safely pruned if shoots or basal cups do not occur closer than 6 inches from the bole. For each 1-inch increase in branch diameter, the minimum safe distance is increased by 2 inches."

In the Pacific Northwest, the U.S. Forest Service has used what is termed here a pruning-felling method of control. This calls for:

1. Removal of infected overstory trees as a part of the timber harvest;
2. Thinning to remove understory trees with
   a. stem infections,
   b. limb infections close to the bole, or
   c. so many branch infections as to make pruning impractical;
3. Pruning infected branches from the remaining trees.

Leave trees are selected by crewmen as they thin; trees are not premarked.

A "felling-only" method is used in a 10-year-old control program underway on the Mescalero-Apache Reservation of New Mexico. Sanitation involves removal of nearly all infected trees in the thinning operation (Hawksworth and Lusher 1956).[6] This results in lower stocking after sanitation, but lower total cost than where pruning is employed.

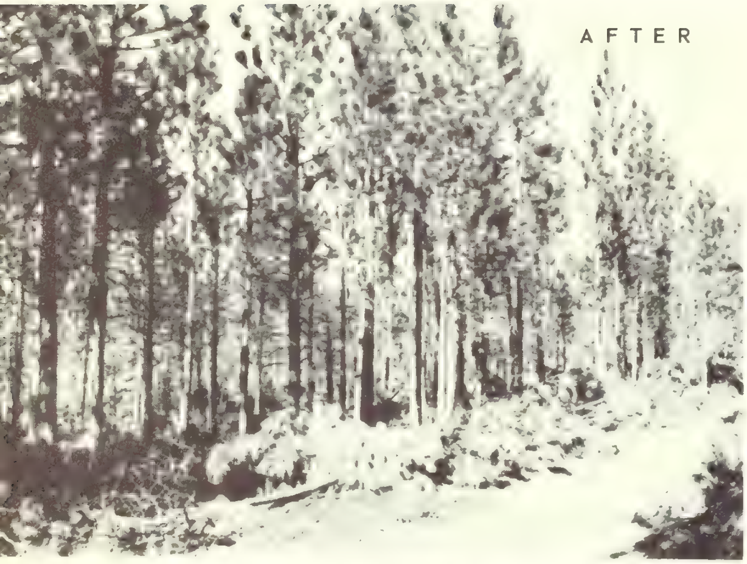
Because infections may remain latent for several years before producing visible shoots, a recleaning must be planned about 5 years after the initial operation (Hawksworth 1961, p.36). Subsequent periodic inspection is desirable.

SANITATION AND SILVICULTURAL THINNING AS JOINT VENTURES

The opinion that dwarfmistletoe control should accompany any silvicultural thinning operation is widely held. This reflects the conviction that thinning is itself a justifiable undertaking in too dense, uninfected stands. In infected stands, dwarfmistletoe control not only removes a source of hazard to uninfected trees but also achieves a possibly desirable reduction in stocking, making the concurrent or subsequent silvicultural thinning costs for the stand as a whole less than those for a comparable uninfected stand. Conversely, silvicultural thinning removes some infected trees.

[6] In actual practice, some 3 to 4 percent of the infected trees were pruned in the Mescalero program.

ESTIMATING THE COST OF DWARFMISTLETOE CONTROL



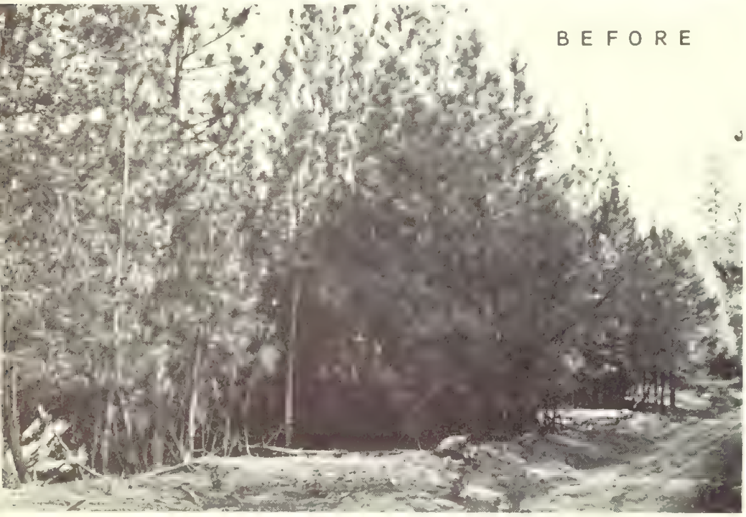


Figure 2.--One of more than 80 young ponderosa pine stands treated in the course of the economic study. Before precommercial thinning and dwarfmistletoe control, this area had 7,000 stems per acre. So dense a stand ordinarily would not be attractive treatment investment opportunity.

Figure 3.--A sectional aluminum pole saw developed by the Deschutes National Forest for pruning infected limbs from lightly infested poletimber-size trees. Such treatment may be desired where (1) the tree has almost reached merchantable size, (2) no other tree of comparable size can effectively use the growing space vacated if this tree were felled instead of pruned, (3) a young understory stand requiring protection from dwarfmistletoe is present, and (4) there is reasonable assurance that all dwarfmistletoe plants can be seen from the ground. Long-pole pruning costs, as compared with costs of alternative felling of overstory trees, are not considered in the report.

In order to identify the cost of dwarfmistletoe control with and without silvicultural treatment, time studies were conducted during 1961 and 1962 on the Deschutes National Forest in eastern Oregon. After overstory removal in timber sales, thinning of trees less than 5 inches d.b.h. was done with powered circular saws commonly called brush-cutters (fig. 2). Next, powered bow saws were employed in removing surplus stems over 5 inches d.b.h. Finally, pruning was done with 7- and 14-foot pruning saws. In a few instances, 40-foot sectional pruning saws were used to remove limited branch infections from otherwise desirable tall trees (fig. 3). The study is described in detail elsewhere.[7]

Data were collected in such a manner as to permit comparing the costs of three kinds of dwarfmistletoe treatment: (1) pruning-felling control, with additional thinning to meet silviculturally desirable stocking levels; (2) pruning-felling control, without silvicultural thinning; and (3) felling-only control, with silvicultural thinning.

COST OF PRUNING-FELLING CONTROL WITH PRECOMMERCIAL THINNING

Because costs of labor and equipment change with time, the numbers of man-hours required per acre for thinning and dwarfmistletoe pruning of infected stands are given in figures 4 and 5. Also shown

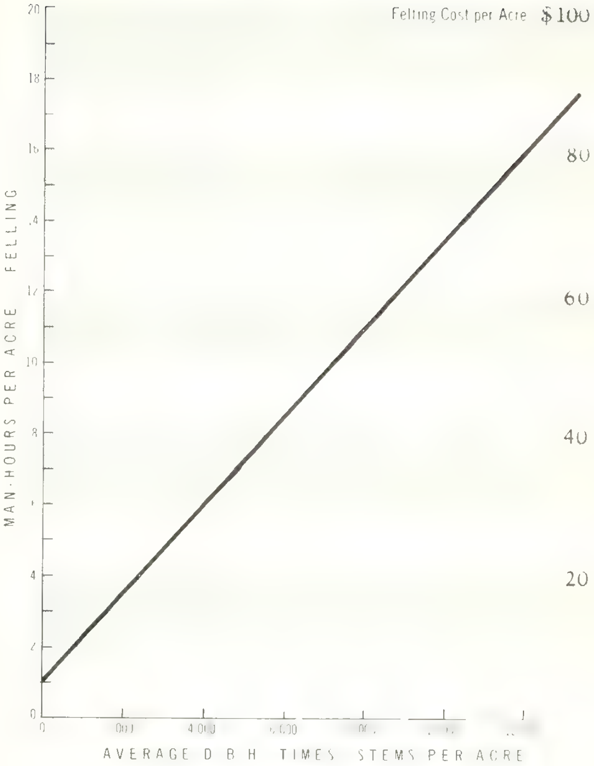


Figure 4.--Pruning-felling control with precommercial thinning; felling operation, time and cost per acre.

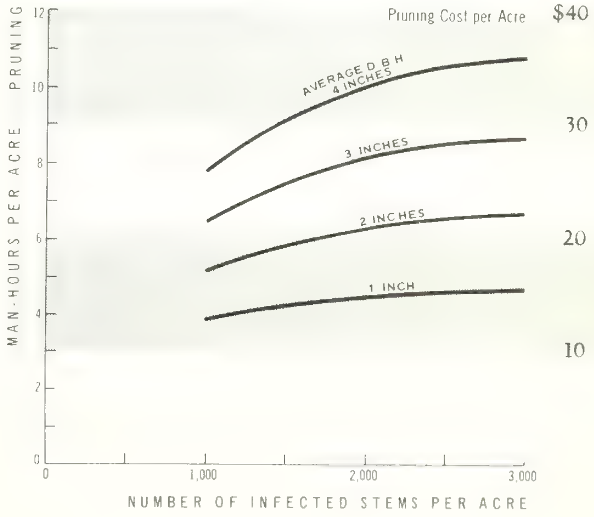


Figure 5.--Pruning-felling control with precommercial thinning; pruning operation, time and cost per acre.

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[7] Dykeman, K., and Simonson, J. Project work plan for study of dwarfmistletoe control costs. 12 pp. 1961. (Unpublished report on file at Deschutes National Forest, U.S. Forest Serv., Bend, Oreg.)

Flora, D.F. Plan for cost analysis, dwarfmistletoe control study. 15 pp. 1961. (Unpublished report on file at Pacific NW. Forest & Range Expt. Sta., U.S. Forest Serv., Portland, Oreg.)

are 1961-62 thinning and pruning costs per acre on the study areas. Costs are exclusive of initial reconnaissance, travel on "company time," vehicle expense, operation of camps, slash reduction, and followup removal of incipient infections.

COST OF PRUNING-FELLING CONTROL WITHOUT PRECOMMERCIAL THINNING

The Deschutes National Forest time-study data were used to estimate the cost of dwarfmistletoe felling and pruning without silvicultural thinning. Pruning time and cost per acre are the same as in figure 5. Man-hours required and cost per acre for the felling portion of control are given in figure 6.

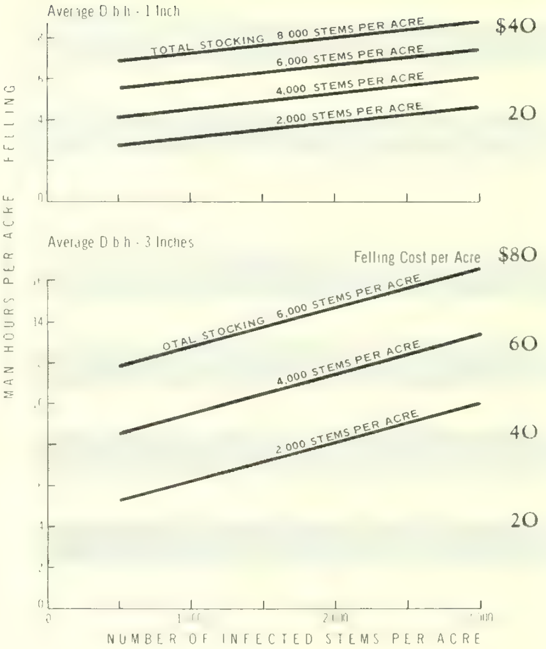

Figure 6.--Pruning-felling control without precommercial thinning; felling operation, time and cost per acre.

COST OF FELLING-ONLY CONTROL WITH PRECOMMERCIAL THINNING

No time studies have been made in the Northwest of this approach to dwarfmistletoe eradication. However, pruning-felling data for thinning in infected stands seem applicable when adjusted upward for the larger number of stems removed in the felling-only method in instances where additional trees must be felled. Figure 7 presents estimated per-acre costs for the felling-only technique, when powered brush-cutters and bow saws are used.

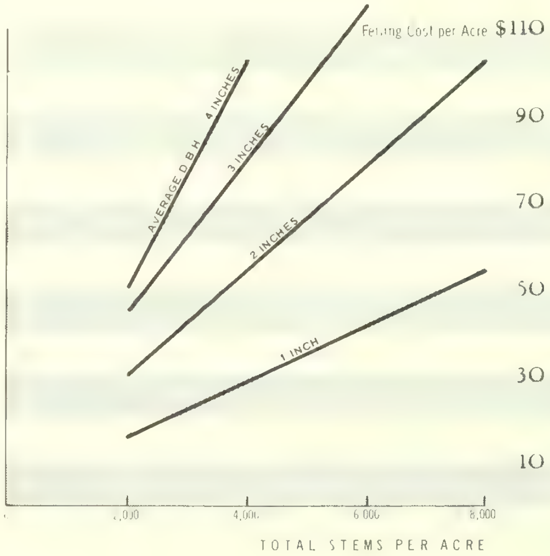

Figure 7.--Felling-only control with precommercial thinning; cost per acre.

ADDITIONAL TREATMENT COSTS

Costs discussed so far are those attributable directly to the acreage treated. There are, however, other costs that cannot be estimated from the character of the timber stand.

Travel Cost

Travel time can be an important cost element. For example, if 30 minutes of each 480-minute workday are spent in transit, a job which formerly took one 480-minute day now requires 510 minutes, so that labor cost increases by 6-1/4 percent.

The cost of vehicles can also be substantial. On the control projects associated with this study, one vehicle was required for every five men. Using a vehicle cost of 15 cents per mile, table 1 presents factors for adjusting the costs of figures 4 to 7 upward for travel. The factors allow for both labor and vehicle costs.

Reconnaissance Cost

The cost of reconnaissance to locate infected areas is not separated in this analysis. It is assumed that, in a large-scale control program, the identification and marking of infected areas is a responsibility of supervisory and overhead personnel. The cost of these persons is included in the cost estimates already presented for each method of control.

Recleaning Cost

A followup operation, about 5 years after the initial sanitation project, is an essential part of a comprehensive dwarfmistletoe control program. The cost of a recleaning, using the thinning-pruning technique outlined earlier, can only be inferred. Estimates of about $5 per acre are commonly used.

Table 1.--Factors for adjusting dwarfmistletoe control costs to include travel cost [1]

Travel time during an 8-hour shift (minutes)	Distance, round trip, miles							
	10	20	30	40	50	60	70	80
15	1.052	1.071	--	--	--	--	--	--
30	1.088	1.109	1.129	1.150	--	--	--	--
45	1.125	1.148	1.170	1.192	1.214	1.236	--	--
60	--	1.191	1.215	1.239	1.262	1.286	1.310	1.334
75	--	--	1.262	1.288	1.314	1.339	1.365	1.391
90	--	--	--	1.342	1.370	1.397	1.425	1.453

[1] Multiply estimated cost without travel by the appropriate adjustment factor. A vehicle and labor cost of 15 cents per mile is assumed.

USING THE COST CHARTS

Pruning-felling treatment cost, with or without precommercial thinning, can be estimated from figures 4 to 6 by using information on just three factors: stems per acre that are infected, total number of stems per acre, and average d.b.h. of all stems. Estimates of these factors can be made by taking plots within each stand. A grid of 1/250-acre plots has been used for this purpose where the average d.b.h. of all stems is less than 5 inches. An intensive survey would not be made, however, until a more general reconnaissance had located infected stands.

To gage the cost of treating a particular stand by the felling-only method, the total number of stems per acre and average d.b.h. of the stand must be obtained. Cost can then be estimated from figure 7.

DISCUSSION

For some areas, such as recreation sites and roadside strips, dwarfmistletoe control decisions depend strongly on factors other than economic returns. This section has explained guides for estimating the cost of dwarfmistletoe control in any stand of sapling-size timber, without considering returns. To use the guides, information must be obtained on stand density and average degree of infection.

Two methods of control, pruning-felling and felling-only, have been discussed. The cost of pruning-felling has been considered, both in combination with and separate from precommercial thinning.

Although the felling-only method is generally less costly, it does not follow that it is more economical. This method removes more trees, thereby lowering returns. The important economic measure, return per dollar of investment, is explored in the next section of this paper.

PREDICTING RATES OF RETURN FROM DWARFMISTLETOE CONTROL

There are two kinds of economic returns from eradication of dwarfmistletoe. One is increased growth and decreased mortality on the treatment area. A second comes from stands close to the treated area that would become infected if the nearby dwarfmistletoe were not removed. These returns are the difference between production if the stands are infected and production if the stands are clean.

Dwarfmistletoe control returns can be determined as follows: On the infected area, the yield from a thinned, infected stand can be subtracted from the yield of a thinned stand with dwarfmistletoe treatment. For nearby uninfected areas, the method is the same except that computations are more difficult because, as time passes, infection moves laterally through the stand and infection intensity increases within the infected part of the stand. Since tree growth and mortality depend on the size of a tree, its competition, and degree of infection, yield differs greatly depending upon distance from the initial infection source.

RATES OF RETURN ON TREATMENT INVESTMENTS

Almost every forester must divide limited funds among many worthwhile activities. His aim is to get maximum forestry benefit for each dollar spent. To meet this objective, he must rank management opportunities according to their profitability; that is, according to the expected rate of return on investment cost. High-ranked projects are undertaken in preference to low-ranked projects. Ranking by rate of return permits not only a choice between different stands being considered for dwarfmistletoe control but also comparison with other opportunities like pruning and site preparation.

Rates of return on dwarfmistletoe control, with or without precommercial thinning, are given in figures 8 to 10, using the cost-of-treatment data presented earlier (for the pruning-felling method because of its widespread use) and biological and economic information summarized below.

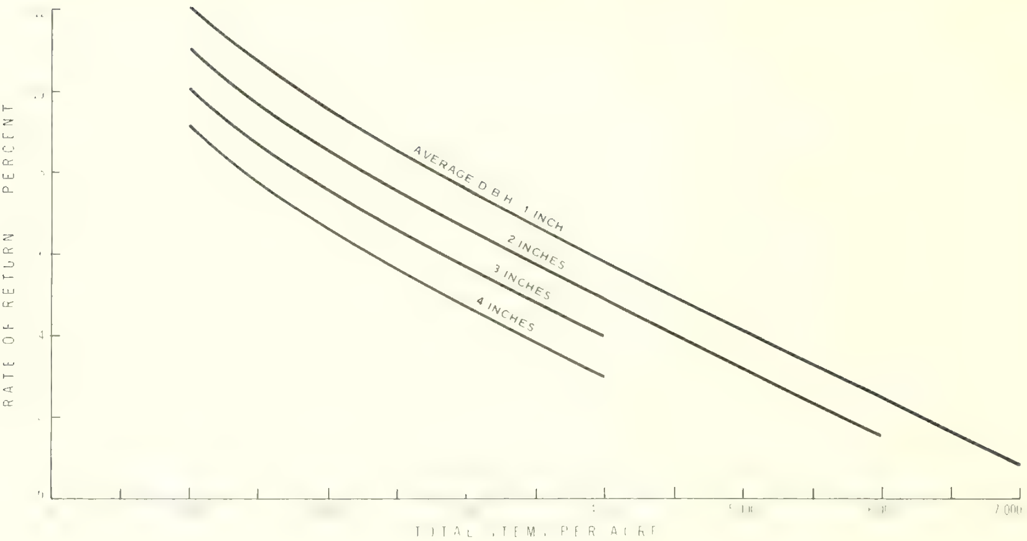

Figure 8.--Rate of return on investment. Dwarfmistletoe control with precommercial thinning. Site IV; size of infected stand, 1 acre. Rule: For each increase of site quality by one class, subtract 1/2 percent; for each increase of size of infected stand by 1 acre, subtract 1/5 percent.

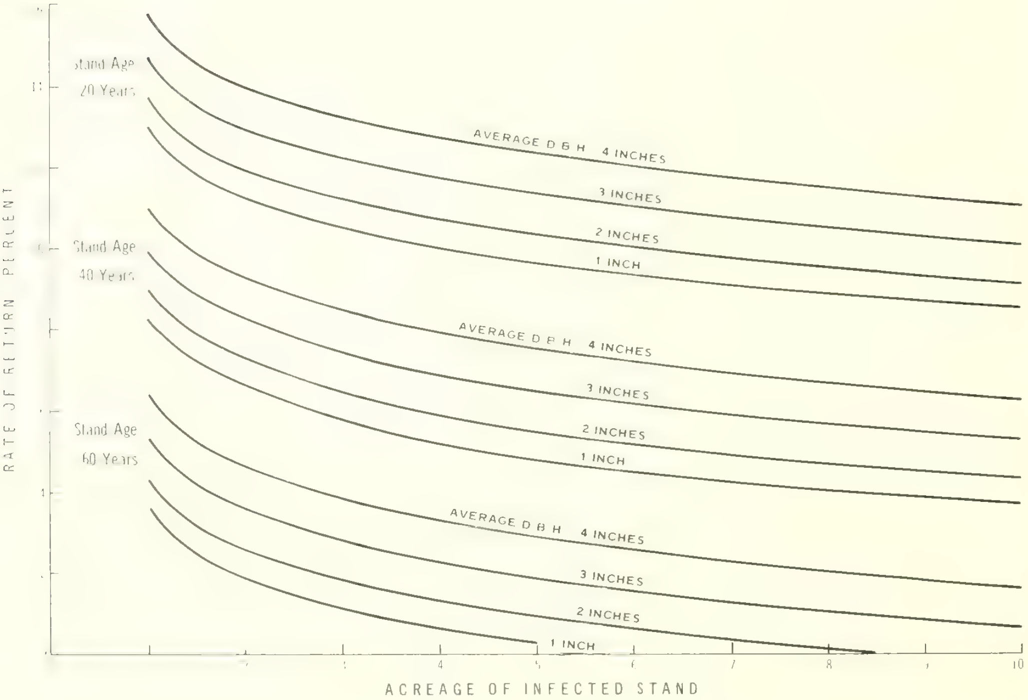

Figure 9.--Rate of return on investment. Dwarfmistletoe control without precommercial thinning. 2,000 stems per acre. Rule: For each increase of stocking by 1,000 stems per acre, subtract 1 percent.

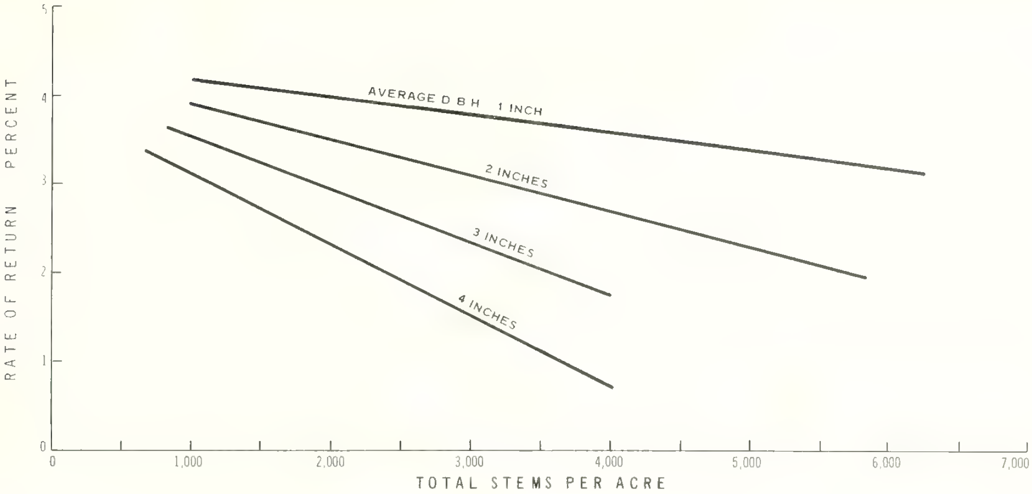

Figure 10.--Rate of return on investment. Dwarfmistletoe control after commitment to precommercial thinning. Site IV; stand age, 20 years. Rule: For each increase of site quality by one class, subtract 3 percent; for each increase of age by 10 years, subtract 1/2 percent.

Figure 10 refers to cases in which policy and budgetary action already call for precommercial thinning of infected stands, so that dwarfmistletoe control involves a separate and subsequent decision. That special consideration is required for such cases is shown by the following example. Suppose that dwarfmistletoe control alone costs $30 per acre and that silvicultural thinning alone costs $30 per acre. However, for the reason of jointness discussed earlier, the two operations together might cost only $50 per acre. If a decision to thin has already been made, and $30 per acre allocated for it, a later decision to add dwarfmistletoe control to the treatment requires adding only $20, not $30, for pest control.

Data

Forest disease researchers at the Pacific Northwest Forest and Range Experiment Station are engaged in dwarfmistletoe investigations from which interim conclusions have been drawn to develop control priorities.

Yield estimates for uninfected, unthinned stands were made from equations developed by Lynch (1958). For thinned, uninfected stands, Forest Service guidelines were employed.[8] Stumpage is valued at $15 per thousand board feet.

INVESTMENT ALTERNATIVES

Three philosophies of treatment are considered. These are:

1. Dwarfmistletoe control concurrent with precommercial thinning.

2. Dwarfmistletoe control in a previously thinned stand, or where a decision to thin has already been made.

3. Dwarfmistletoe control without precommercial thinning.

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[8] U.S. Forest Service. National Forest timber stand improvement handbook, Region 6, 1965. Timber management handbook, Region 2, 1956.

COMPUTATIONS

Determination of the rate of return on a stand-treatment investment requires projecting stand growth through a rotation, with and without treatment. Next, economic value must be assigned to the yield differential. For a public agency, the economic impact of stand treatment is its effect on the allowable cut. Dwarfmistletoe control is generally followed by marked increase in growth on the treated area. Because anticipated growth enters the allowable cut calculation, an expected growth increase on part of a working circle must affect the overall allowable cut to some degree. Even if treatment of a juvenile stand produces no immediate change in merchantable yield from the stand treated, the resulting change in calculated allowable cut leads to an immediate increase in merchantable timber cut from other stands.[9]

Calculations made for this publication incorporated the foregoing allowable cut consideration. Rates of return presented here would be inapplicable to forest managers whose cutting plans are not affected by growth estimates.

The cost, growth response, economic impact, and rate of return on investment were calculated for over 4,000 young stands for each of the three control philosophies. Stands differed according to site class, age, average d.b.h., degree of infection, stocking level, size of infected area, and distance from town. The last factor affects both travel cost for crews doing stand treatment and hauling cost of logs sold.

Results of the stand projections and rate-of-return calculations were used to develop rate-of-return charts, figures 8 through 10. It was found that some factors--for example, degree of infection--are not significantly helpful in predicting the rate of return on treatment investment. Hence, such factors are not employed in the charts.

USING THE CHARTS

Assignment of treatment priorities to individual stands requires a type map or a list of stands identified as to location. In either case, information about each stand must be obtained from field examination, previous experience in the area, or in some instances from aerial photographs. The kinds of information needed can be determined by examining the charts. For example, to use figure 8, one must know site quality, average d.b.h., stocking in stems per acre, and the acreage involved.

Arabic numerals along the vertical axes in figures 8 to 10 indicate rate of return in percent on treatment investment. Stands with high numbers should receive high priority for treatment.

Obviously, rigid use of the charts is possible only where (1) stands are accessible, (2) cutting plans permit overstory removal before treatment of juvenile stands below, (3) commercial timber production is the principal objective of stand management, and (4) assumptions made in this report are valid.

---

[9] No real increase in cut would be created in a working circle lacking a backlog of merchantable timber, but this circumstance is rare in the West.

SUMMARY-- STEPS TO FOLLOW IN USING THE GUIDES

ESTIMATING THE COST OF DWARFMISTLETOE CONTROL

1. From column 1, below, select the kind of stand treatment to be used.

2. Collect the types of information about each infected stand indicated in column 2.

3. With the data for each stand, use the chart(s) listed in column 3 to estimate that stand's treatment cost per acre.

4. Multiply treatment cost per acre by the acreage of the infected stand to obtain total cost of treating the stand.

5. Multiply treatment cost by an adjustment factor from table 1.

6. Add about $5 per acre for each recleaning anticipated.

COLUMN 1-- kind of treatment	COLUMN 2-- stand data to collect	COLUMN 3-- use figure(s)
Pruning-felling with precommercial thinning	Average d.b.h.; total stems per acre; infected stems per acre	4, 5
Pruning-felling without precommercial thinning	Average d.b.h.; total stems per acre; infected stems per acre	5, 6
Felling-only with precommercial thinning	Average d.b.h.; total stems per acre	7

ESTIMATING RATES OF RETURN ON INVESTMENT IN DWARFMISTLETOE CONTROL

1. From column 1, below, select the kind of investment to be made.

2. Collect the types of information about each infected stand indicated in column 2.

3. With the data for each stand, use the chart(s) listed in column 3 to estimate the rate of return on investment involved in that stand.

4. List the stands by their location and estimated rate of return, starting with the highest return stand and working down.

5. Schedule for earliest treatment those stands appearing first in the list.

6. In general, treat only stands that are within one-fourth mile of a suitable access road. Treatment cost increases disproportionately as walk-in distance increases, reducing return on investment to unattractive levels.

COLUMN 1-- kind of investment	COLUMN 2-- stand data to collect	COLUMN 3-- use figure
Control with precommercial thinning	Average d.b.h.; total stems per acre; site class; acreage of infected stand	8
Control without precommercial thinning	Average d.b.h.; total stems per acre; site class; acreage of infected stand; stand age	9
Control after a commitment has been made to thin precommercially	Average d.b.h.; total stems per acre; site class; stand age	10

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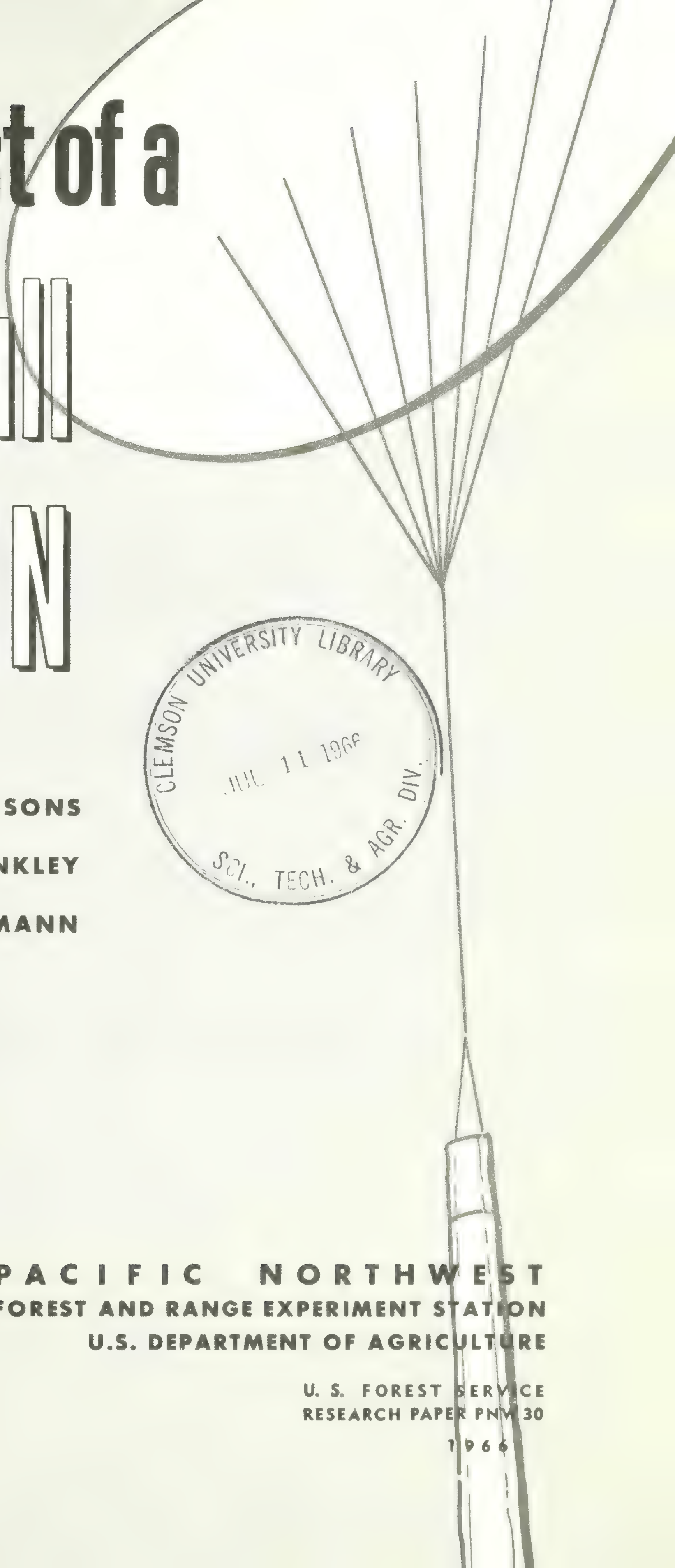
logging test of a single-hull BALLOON



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PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE

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INTRODUCTION

This test of a single-hull balloon for logging was performed early in 1965 in connection with the forest engineering research study of harvesting heavy timber from difficult access areas. Prior to this test, the only balloon logging experience in the United States was that acquired by Bohemia Lumber Co., using a twin-hull Vee-Balloon designed and built by Goodyear Aerospace Corp. Single-hull balloons had been tested in British Columbia in 1963 and 1964, but specific performance information was unavailable. The test reported here was conducted by the U.S. Forest Service, Pacific Northwest Forest and Range Experiment Station, in cooperation with the Bohemia Lumber Co., Inc., of Culp Creek, Oreg. Site of the test was at Dean Creek on the Elliott State Forest near Reedsport, Oreg.

Primary test objectives were:

1. To obtain information for a dynamic analysis from which parameters for logging balloon design could be established. (Attempts to analyze the lift-off phase had previously required assumptions too numerous for a valid analysis.)

2. To determine limiting windspeeds when the balloon was yarding, tethered, and bedded down.

3. To determine structural and aerodynamic characteristics of this hull type.

4. To determine payload capability under various operating conditions.

5. To obtain logistics and reliability information.

This test was not intended to prove or disprove the suitability of this particular balloon for logging, but was intended to evaluate the characteristics of the single-hull design. The experiment was prompted by a report[1/] which indicated that a single-hull balloon of proper design merits careful consideration for logging operations.

Logging costs were not obtained because such information would be premature at this stage of balloon system development.

[1/] Ganzer, Victor M. Preliminary survey of single-hull vs. Vee-Balloons for logging applications. 1965. (Unpublished report on file at Pacific Northwest Forest & Range Exp. Sta., U.S. Forest Serv., Portland, Oreg.)

APPARATUS USED IN TEST

The apparatus used in this test will be described as: (1) operational equipment, (2) balloon support equipment, and (3) test support equipment. Operational equipment is defined as that necessary to perform yarding with a balloon. Balloon support equipment is that peculiar to balloon logging, not necessary to the yarding operation but required at other times. Test support equipment includes all of the apparatus used to gather data.

Operational Equipment

Figure 1 shows the arrangement of operational equipment used in this test. The various components are described in detail below.

Balloon.--The single-hull balloon was purchased from MacMillan, Bloedel & Powell River, Ltd., of Canada, upon completion of their 1964 logging tests. This balloon was designed and manufactured in England in 1958 for use of the British Atomic Energy Authority at the Christmas Islands Test Area. MacMillan, Bloedel & Powell River purchased the balloon through Air Reel Transport, Ltd., in October 1964, and used it for logging during November and December until heavy snow halted operations. Testing with this balloon at the Dean Creek site began in February 1965.

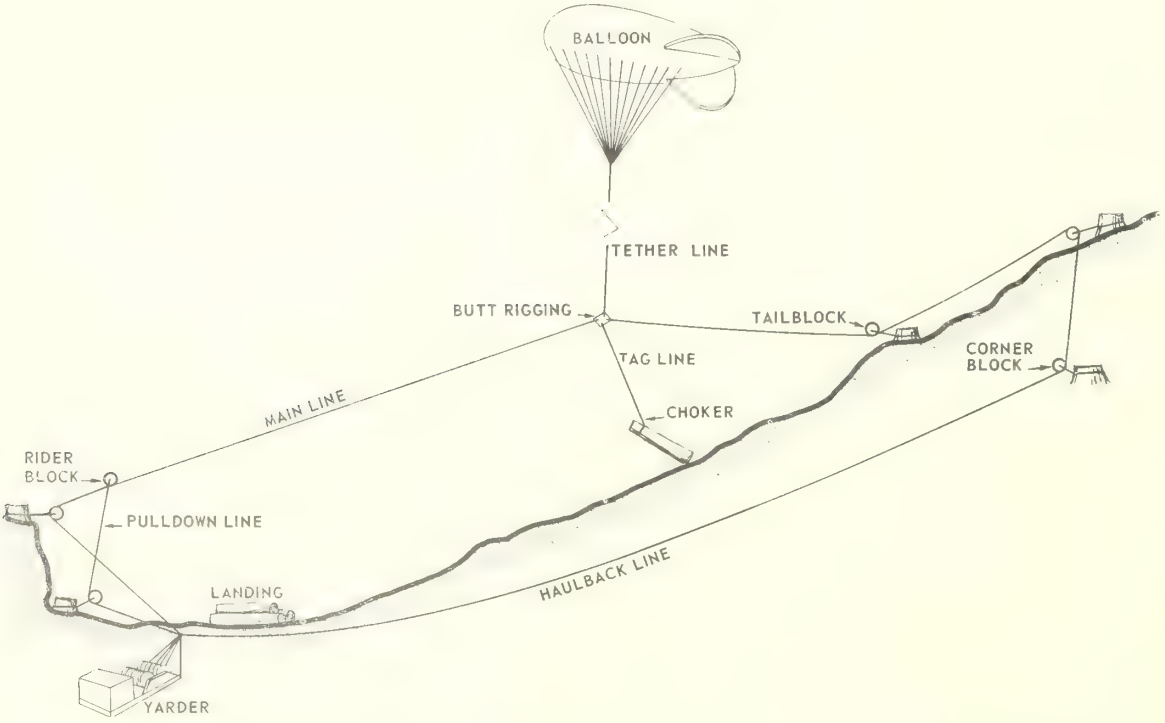


Figure 1.--Arrangement of operational equipment for single-hull balloon test.

Configuration of this British balloon is typical of the majority of tethered balloons. The balloon consisted of a streamlined hull with three inflatable tailfins. A ballonet, or air-filled compartment, was incorporated in the lower portion of the hull and was separated from the gas section by a diaphragm. Ram-air, which entered through an airscoop, pressurized the ballonet to maintain the hull shape in wind. The ballonet also provided a variable hull volume for expansion and contraction of the gas. The tailfins were also inflated by ram-air and could be collapsed for bedding down. The balloon fabric was coated, two-ply, Egyptian cotton. Figure 2 shows the balloon just after release from the bedding ground with the tailfins deflated. In figure 3, the balloon is shown just before bedding down with the tailfins inflated.

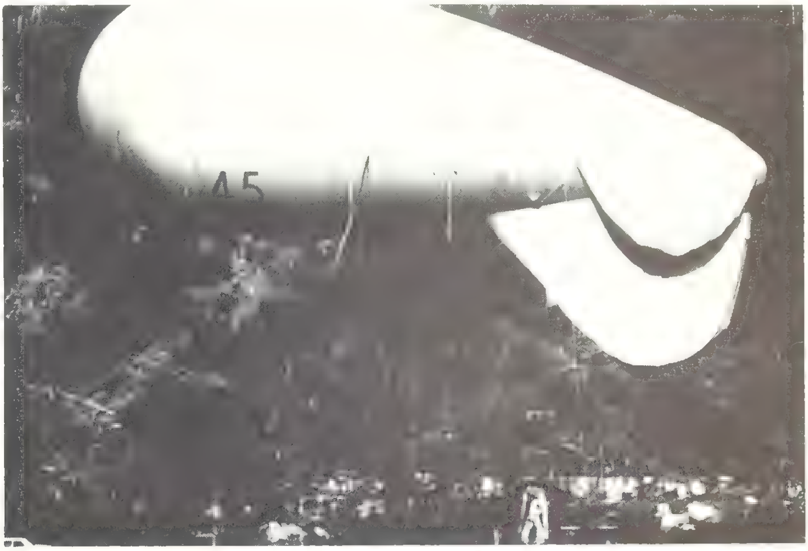


Figure 2.--Single-hull balloon just after release from bedding ground with tailfins deflated.

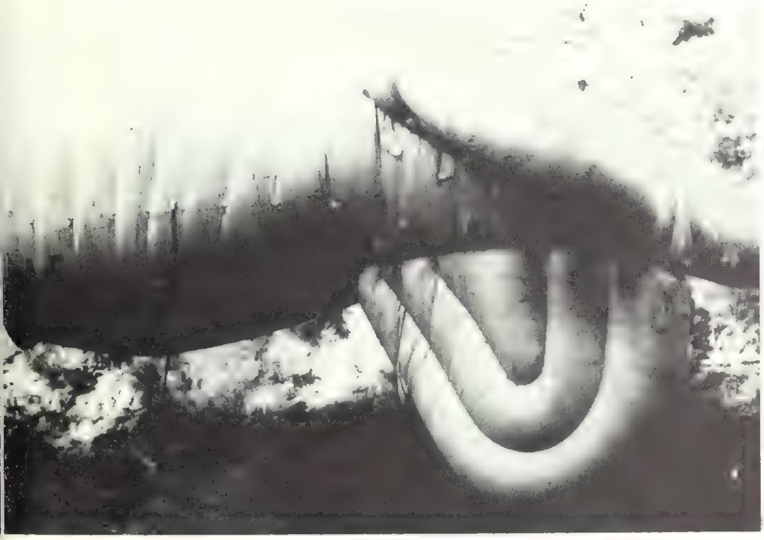


Figure 3.--Single-hull balloon just before bedding down with tailfins inflated.

A suspension system, consisting of twenty-four 1/8-inch-diameter steel cables, was used between the tether line and the balloon. At the balloon, the suspension cables were fastened to load patches which spread the load over an area of the balloon fabric. Two sets of ground handling lines were provided on the balloon and also attached to load patches. One set pulled the balloon to the ground at the bedding area, and the other set secured the balloon to anchors after it was lowered. The various lines can be seen in figures 4 and 5. The suspension lines attach to the lower patches seen in these figures, and the handling lines attach to the middle and upper patches.

No maintenance other than routine inspection was performed on the balloon before initial inflation. It soon became apparent, by the large volume of gas lost, that painting of the balloon was required. Hypolon paint was applied to the balloon after about 4 weeks of testing.

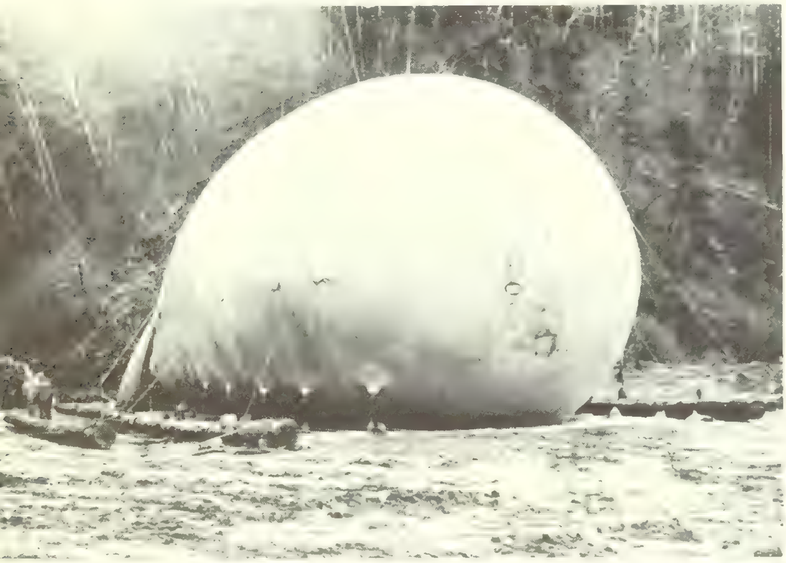
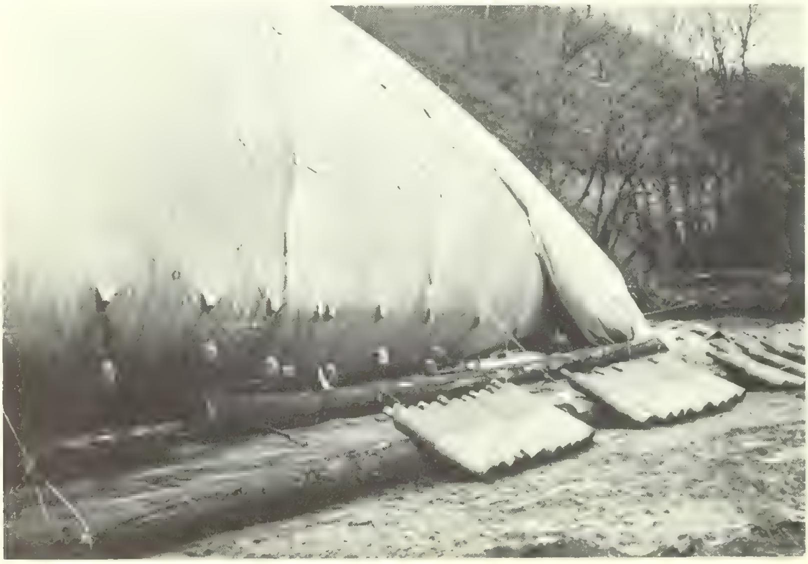


Figure 4.--Front view of single-hull balloon tied down at bedding ground.

Figure 5.--Side view of balloon secured at bedding ground. Cylinders contain helium for replenishment.



Yarders.--Two yarders, manufactured by Washington Iron Works of Seattle, were used during the test period. Initially, a modified skyline yarder with a maximum main-line speed of 1,800 feet per minute was used; this was later replaced by a yarder, designed specifically for balloon logging, which had a maximum line speed of 2,500 feet per minute. The skyline yarder is shown in figure 6.

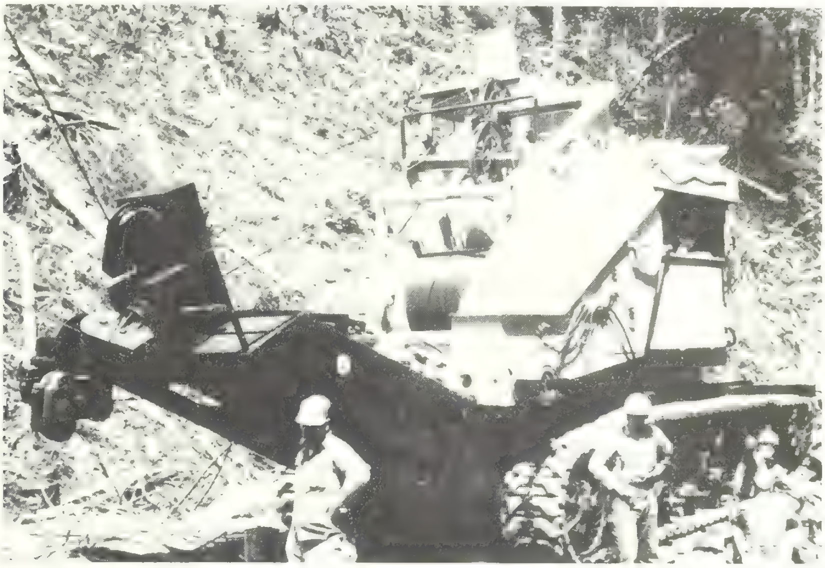


Figure 6.--Tank-mounted balloon yarder, designed and built by Washington Iron Works of Seattle, Washington.

Rigging.--As shown in figure 1, the rigging was similar to that used in high-lead yarding, except that the balloon tether line was attached to the butt rigging and provided lift at this point. A 1/2-inch-diameter main line and a 9/16-inch-diameter haulback line were used with both yarders. Two 1/2-inch tether lines were incorporated between the butt rigging and the balloon suspension (one as a load line, and the second as a safety line to prevent loss of the balloon in the event of failure of the load line). Tag lines varied from 50 to 150 feet, depending on the terrain and landing areas.

Communications.--A radio link provided voice signals between the yarder operator and the choker setters.

Balloon Support Equipment

The balloon support equipment consisted of equipment required at the bedding area and that required to transfer the balloon between the bedding ground and the logging site.

Bedding area equipment.--The bedding area was covered by a ground cloth to protect the hull fabric from possible chafing and puncture. Logs anchored the tiedown lines and also secured blocks through which the pulldown lines passed. A crawler tractor, to which the pulldown lines were attached, was used for the actual pulldown operation and remained in position while the balloon was bedded down. Sandbags secured the deflated tailfins and stabilized the balloon in high winds. Figures 4 and 5 show the balloon bedded down.

Transfer equipment.--A truck with a two-drum winch transported the balloon between the bedding ground and the logging site. A 3,000-pound counterweight was placed at the rear of this truck to counteract the balloon lift and sidepull in a wind.

Test Support Equipment

Test support equipment consisted of a 16-mm. movie camera, a dynamometer, a staff compass, two recording anemometers, and forms for recording test data. One anemometer was located at the bedding area and recorded the average windspeed at 15-minute intervals. The other anemometer, capable of providing continuous velocity readings, was located at the logging site on a ridge approximately 1,000 feet above the landing.

TESTS

All the various tests performed in this study were part of an actual logging operation. This is not always the most favorable way to conduct engineering research, but available funds did not allow for performing any portion of the test in a more completely controlled environment.

Logging tests were conducted on two units of the Bohemia Lumber Co.'s timber sale in the Elliott State Forest. The first unit was located at the head of a small stream drainage with steep, broken slopes. The position of the landing and presence of small side ridges in this unit required that some turns be started from the far side of the ridges, and nearly all turns had to pass over side ridges on the way to the landing. The maximum yarding distance in the first unit was approximately 2,000 feet. In the second unit, yarding was done from a facing hillside with a landing at the bottom of the slope. The maximum distance yarded in this unit was approximately 1,200 feet. In both units, the direction of yarding was basically east, and prevailing winds were either from east or west. The bedding area was located approximately 1 mile from the logging units.

Operating and supervisory personnel of the Bohemia Lumber Co. performed the logging and balloon handling, and Forest Service personnel observed the tests and collected data. Testing was also witnessed by representatives of several balloon manufacturers.

Duration of the testing was to have been not more than 3 months, beginning on or about February 8, 1965. The balloon arrived on this date and was in operation until March 3, 1965, when operations were suspended to paint the balloon and to await arrival of the new balloon yarder. Operations resumed on April 21, 1965, and continued until May 4, 1965, when a total balloon failure ended the tests.

Survival Test

This test was conducted to establish the safe wind limits while the balloon was yarding, while it was tethered in the unit, and while it was bedded down and, also, to point out potential stability and structural problems inherent in this hull design. The operation was observed and events indicating survival problems were recorded. In this report, the term "survivability" is used as a measure of the ability of the balloon to withstand the effects of wind.

Operational Test

The operational test was performed to obtain a cycle time and maximum payload comparison between turns which were yarded with one end in contact with the ground and those which were yarded free of the ground. Selected logs were weighed and a record kept of the manner in which they were yarded.

Lift-Off and Flying Test

The purpose of this test was to determine the relationships of the various forces acting during the initial phases of log motion and to determine the approximate magnitude of the drag resistance encountered in flying logs on downhill slopes. Attempts were made to carry out this test by photographically recording the relative angles of the lines and by weighing selected logs.

Logistics Test

The logistics test was performed to indicate the support and maintenance requirements of the single-hull balloon. The test was conducted by observing and recording setup, scheduled maintenance, initial gas inflation and replenishment, and transfer operations between bedding ground and logging unit.

Reliability Test

This test was performed to indicate the reliability of the single-hull design. A record was kept of each balloon failure, its cause, and the yarding time lost due to the failure.

RESULTS AND DISCUSSIONS

During the first phase of testing, the only serious problem was the excessively high rate of gas leakage. At the start of the second phase, the Forest Service requested the operator to see if the balloon's structural capability could be reached by inducing the heaviest possible loads. When this procedure was followed, a series of small balloon failures resulted, which, together with the intentionally severe loading, resulted in a complete failure.

Table 1 presents a general time study of the single-hull balloon test. The table was compiled from daily log sheets kept during the test. Times were divided into the following categories:

Setup.--Time required for inspection, initial inflation, and arrangement of bedding ground after which the balloon was available for yarding.

Balloon scheduled maintenance.--Time required for preventive maintenance, including gas replenishment and inspection.

Balloon handling.--Time required to make the transition between a secured, tied-down status at the bedding ground and an operational status in the unit.

Balloon unscheduled maintenance.--Time required for corrective maintenance following repairable balloon failures.

Wind delays.--Periods when winds prevented yarding or moving the balloon from the bedding ground.

Road changes and equipment maintenance.--Time required to correct malfunctions of the rigging and yarder as well as time for block and road changes and yarder moves. Also included in this item are all miscellaneous delays not caused by the balloon, such as radio malfunctions.

Actual yarding.--Time during which yarding took place.

Survival Test

The survival test did not furnish data as complete as desired due to failure of the wind-recording instruments and, in some cases, lack of sufficient winds to cause survival problems. The anemometer at the logging unit was to record both speed and direction. However, the direction recorder failed to function entirely, and the speed readings appeared to be in error. A post-test repair and calibration of this anemometer verified its poor condition at the time of the test and pointed out the need to adequately check out instrumentation before testing begins. Due to the instrumentation problems, windspeeds for the survival tests were estimated.

Table 1.--General time study of single-hull balloon test on Elliott State Forest, Oregon, 1965

(Hours)

Date	Setup	Balloon scheduled maintenance	Balloon handling	Balloon unscheduled maintenance	Wind delays	Road changes and equipment maintenance	Actual yarding
First phase:							
Feb. 8	4.0	0	0	0	0	0	0
9	8.0	0	0	0	0	0	0
10	9.0	0	0	0	0	0	0
11	4.0	0	0	0	0	4.0	0
12	0	1.3	1.3	0	0	2.8	2.6
13	0	0	1.0	0	0.8	1.4	4.3
15	0	1.5	1.3	0	0	1.6	4.1
16	0	1.0	1.2	0	0	1.0	5.3
17	0	.5	1.0	0	0	3.7	3.3
18	0	1.2	.3	0	0	2.1	4.9
19	0	0	.5	0	0	1.3	6.2
20	0	0	0	0	0	8.0	0
22	0	.5	0	0	0	7.5	0
23	0	1.0	1.2	0	0	4.9	.9
24	0	0	0	0	0	8.0	0
25	0	0	1.3	0	0	6.2	1.5
26	0	.5	1.5	0	2.0	3.4	1.1
Mar. 1	0	.5	1.0	0	5.2	0	1.8
2	0	.5	.5	0	3.0	.8	3.7
3	0	0	1.0	0	0	4.5	2.5
Second phase:							
Apr. 21	0	0	1.0	0	0	0	3.0
22	0	0	1.0	0	0	1.0	6.0
23	0	.5	1.0	0	0	1.0	6.0
26	0	.5	.5	0	0	4.0	3.0
27	0	0	0	0	0	2.5	5.5
28	0	0	0	5.5	0	1.5	1.0
29	0	.5	1.5	0	0	1.5	4.5
30	0	0	0	0	0	8.0	0
May 3	0	.5	.5	3.0	0	.5	4.0
4	0	.5	.5	.7	.3	0	.5
Total	25.0	11.0	19.1	9.2	11.3	81.2	75.7

When winds reached a velocity estimated at 15 miles per hour, the flight path of the balloon became erratic. Yarding was stopped to prevent injury to personnel due to unpredictable line movements and, also, to prevent fouling the tether line in trees near the landing. During these periods, the balloon was allowed to rise to approximately 1,500 feet above the landing by letting out the main and haulback lines. When this height was reached, the balloon became stable. This behavior indicated that a longer tether line would enable logging to continue in winds higher than the 15 miles per hour which, in this test where a 500-foot tether line was used, caused a stoppage in logging operations.

The anemometer at the bedding ground worked intermittently, and readings obtained were judged to be low; therefore, estimates of wind velocity at the bedding ground had to be substituted for actual data. The maximum windspeed encountered during periods when the balloon was bedded down was estimated to be a steady 15 miles per hour with gusts up to 30 miles per hour. The problems encountered in this wind were: movement of anchor logs not secured to the ground, movement of the balloon over the inboard anchor logs, and violent flapping of the deflated tailfins which had pulled loose from the anchoring sandbags. Later, sandbags were hung from the pulldown-line attachment points on the balloon, as shown in figure 5. It is believed that this would have prevented some of the balloon motions. However, high winds did not occur again before the end of the test. Problems caused by wind at the bedding ground point out the need to study use of natural or constructed wind barriers and deflectors. A better system is required for securing the deflated tailfins.

While the balloon was being moved between the logging site and the bedding ground, any crosswind, coupled with the forward motion of the truck, resulted in a circular oscillation of the balloon. On several occasions, the truck had to be stopped to prevent fouling of the tether line in the trees. Side motions of the balloon caused by wind had a tendency to lift one side of the truck. Transfer operations between the truck and the butt rigging in a wind were complicated by swinging of the tether lines.

These experiences indicated that, if the balloon was to be bedded down for a severe wind, it would have to be moved and secured when conditions were still reasonably calm. Best survival in wind was obtained when the balloon was tethered about 1,500 feet above ground.

Operational Test

In the operational test, yarding logs completely free of the ground (flying) was compared with yarding with one end in contact with the ground (dragging). Payload capability and cycle times were compared by weighing selected logs and performing a limited time study of the operation.

This procedure indicated a payload limit of approximately 4,500 pounds for flying and approximately 6,100 pounds for dragging. Static lift of the balloon was approximately 2,400 pounds at the time these logs were yarded. This is only an indication of the payload capability of the balloon, since capability depends on the slope, inhaul speed, and wind velocity. Both of the payloads mentioned above were yarded with an average slope of 30 percent, a yarding distance of approximately 1,200 feet, and calm wind conditions. Flying induced almost no dynamic loads into the balloon after the log was free of the ground, but dragging produced loading which became severe when hangups occurred.

Inhaul speeds for dragging logs were lower than for flying logs to avoid log breakage. However, since inhaul was a relatively small portion of the total yarding cycle time, the difference between dragging and flying cycle times was not appreciable. The average cycle time was 6 minutes with an average yarding distance of about 1,200 feet. Loads averaged 1.48 logs per cycle during the test.

A few logs were carried back up the hill, after being yarded down to the landing, to obtain a comparison between uphill and downhill yarding. Analysis before the test had shown that, in downhill logging, components of the balloon dynamic lift, drag, and inertia all combine with the static lift to provide an upward force on the log. However, uphill logging produces drag and inertia components which act opposite to the static lift. This analysis was verified by the comparison. It was observed that logs easily flown downhill had to be dragged slowly back up the hill. The reduction in speed was necessary to keep the downward drag force component from exceeding the lift forces. Therefore, uphill yarding resulted in an increase in yarding time and a decrease in payload capability. These field observations and analysis indicate that only downhill yarding should be considered when a balloon yarding system similar to that used in this test is to be employed.

Lift-Off and Flying Test

The lift-off and flying test failed to determine, through photographic records of line angles, the relationship of forces which occur while yarding. Factors contributing to the failure of this test include: inaccessibility of the proper position for taking photographs, due to terrain features and safety considerations; inclement weather; insufficient contrast between lines and background; and poor resolution of the equipment used. The failure of this test resulted in a study to determine better methods and equipment for obtaining load data. This study indicated that load cells in conjunction with a telemetric data link would best furnish the desired information, and equipment of this type is presently being acquired for use on future balloon tests.

Logistics Test

The logistics test, to determine the maintenance and support required by this type balloon, was conducted by observing and recording: (1) steps performed to first make the balloon available for yarding; (2) requirements for scheduled maintenance; (3) the quantity of gas for initial inflation and replenishment; and (4) the time required to transfer the balloon between the logging unit and the bedding ground.

Twenty-five hours were required to provide initial balloon availability. The following tasks were performed during this period:

1. Spread ground cloth and uncrated balloon
2. Inflated balloon with air, inspected for leaks, and deflated balloon
3. Inflated with helium
4. Arranged holddown logs and turned balloon and bedding area to face predominant wind
5. Replaced one handling line
6. Attached tether lines to suspension system

"Scheduled maintenance" refers to preventive maintenance which is normally scheduled so that it will not interfere with logging. In this test, a maintenance schedule was not established before the test, but routine preventive maintenance, such as replenishment of helium, periodic inspection, and minor repairs, was recorded as scheduled maintenance. This term is used to distinguish preventive maintenance from unscheduled or corrective maintenance which generally causes a stoppage in logging. During the operation, 11 hours of scheduled maintenance were required, primarily for helium replenishment.

Initial inflation was performed by filling the balloon until it appeared to have the proper shape and tightness. No metering device was used during the filling operation, and the amount of gas used for initial inflation was not known until several weeks later when the billing was received. The amount of gas used and the high initial static lift indicated that the balloon was overfilled during initial inflation. A total of 83,944 cubic feet was used for initial inflation, which resulted in a static lift of 3,300 pounds on the day following inflation. It was found during the test that the balloon was properly inflated when it had a static lift of approximately 2,500 pounds. With this static lift, the balloon was quite soft when bedded down but would attain the proper shape and firmness when the ballonet became pressurized by ram-air during operation. Use of a gas as expensive as helium requires development of better procedures to avoid overfilling a ballonet-type balloon. The time to inflate the balloon was less than 1 hour.

During the first phase of testing, an excessive amount of helium was required for replenishment. Painting the balloon significantly reduced gas leakage. During the test, 110 cylinders of helium, each containing 285 cubic feet of gas at standard atmospheric temperature and pressure, were used for replenishment.

Moving and bedding the balloon required 19.1 hours. This represents about 8 percent of the total test time. If the balloon had been allowed to remain in the logging unit overnight and brought down only for weekends, this time would have been reduced to about 2 percent. In this test, almost daily bedding was required for gas replenishment. This points out the requirement for low-permeability materials in logging balloons as well as development of a reliable balloon which will not have to be bedded frequently for inspection and repair.

Reliability Test

The reliability test was undertaken to obtain an indication of the reliability inherent in the single-hull design. High reliability and survivability are essential qualities which must be developed and designed into a logging ballon if this type of logging is to be economically successful. Other desirable characteristics will mean little to an operator if logging is continually interrupted by balloon down-time to make repairs or by instability in relatively calm winds.

The term "indicated reliability" is used in this report because, in an engineering sense, "reliability" means the probability of a system functioning in a prescribed manner for a specified period of time. Probability numbers cannot be obtained from a single test of a piece of equipment. However, reliability can be indicated by the amount of time required to perform unscheduled maintenance and by noting failure types and occurrence patterns.

Table 1 shows that 9.2 hours were required to perform unscheduled maintenance on the balloon, which was 4 percent of the total test time. No unscheduled maintenance was required during the first-phase testing, and it was only after severe balloon loading was induced in the second phase that unscheduled maintenance was required. The low requirement for unscheduled maintenance was attributed to the overall design simplicity of the balloon.

A modified skyline yarder was used during the first phase of testing, and a yarder designed and built specifically for balloon logging by Washington Iron Works of Seattle was employed during the second phase. With the modified skyline yarder, a series of delays occurred due to lines being fouled, stranded, and kinked. When this yarder was replaced by the balloon yarder, time lost for line maintenance was greatly reduced. The 8-hour delay, shown in table 1, on April 30 was required to move the yarder to a new unit.

Balloon failures near the end of the test were attributed primarily to the age of the balloon and the apparent lack of preventive maintenance during its life. It is believed that if this had been a new balloon or if the test budget had allowed a complete refurbishment prior to testing, the balloon would not have been destroyed.

During the early part of testing, previous lack of maintenance was evident. Inspection of the bag prior to initial inflation showed numerous pinholes in the fabric. Lines to hold the tailfin airscoop were missing. A seam in the side of the hull was partially delaminated. The suspension cables attach to the patches by means of a short length of fiber rope, and one fiber rope was found to be nearly severed by the cable.

On April 24, one of a series of pressure-limiting valves in the hull below the ballonet fell out during yarding. This created a loss in the ballonet pressure, causing the balloon to become too limp for yarding. The balloon was moved to the bedding ground where the necessary repairs were made.

On May 3, the left forward suspension cable broke during yarding. Inspection showed the cable to be badly corroded. The balloon was moved to the bedding ground where the cable was replaced.

On May 4, the tail section was torn completely off during yarding. A log, which was being dragged at the time, hung up on a stump. In working the log free with the main and haulback lines, slack was pulled in the tether line. This allowed the balloon to rise freely in a noseup attitude. At the instant that slack was removed from the tether line by the free rise of the balloon, the main line was accelerated by the yarder. A severe impact load resulted; and since the balloon was in a noseup attitude, only the front suspension lines received this load, resulting in a failure of the front suspension lines as well as violent pitching and rolling of the balloon. This motion and the tension in the tether line caused failure of most of the remaining lines as well as one of the suspension line attachment patches. Finally, a patch near the tail of the balloon was torn out, initiating a tear which continued around the entire hull. Figure 7 shows the balloon after the failure. Repair was considered impractical due to the age and condition of the balloon.

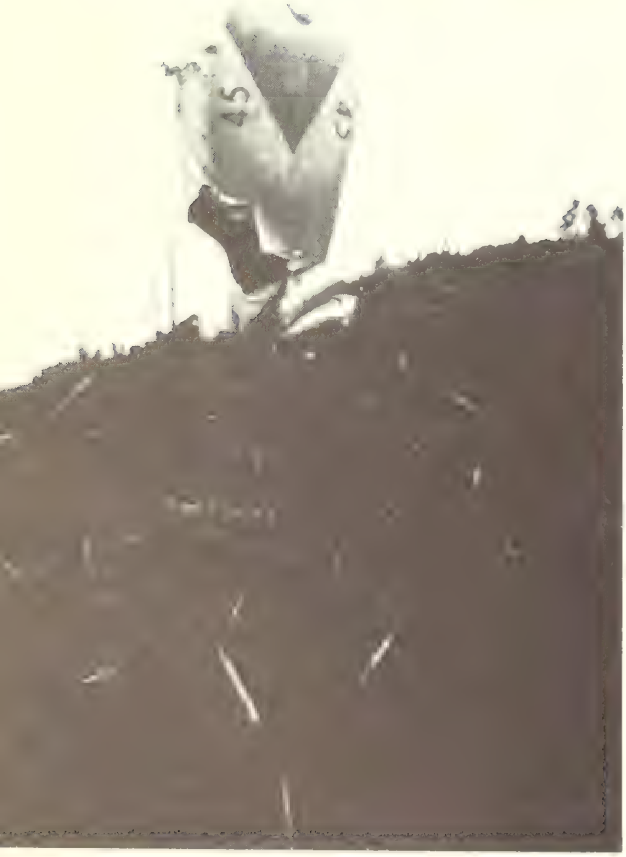


Figure 7.--Single-hull balloon after failure which ended testing.

The failure, which resulted from an impact load when the balloon was in a noseup attitude, might have been avoided if the suspension cables had not been in a weakened condition due to age and corrosion. Since a noseup attitude will always result when the balloon is allowed to rise freely, and since a suspension system designed for loading in a near horizontal attitude cannot distribute loads evenly when the balloon is in a noseup attitude, loading of this type should be avoided.

This failure occurred during planned severe loading tests and in no way reflects on Bohemia Lumber Co.'s fine performance. The failure proved valuable in that it resulted in the development of a new concept of loading and log lift-off which should prevent such failures and still safely permit the handling of heavier log loads.

It was suspected that the cotton balloon material was structurally weak due to its age, but laboratory tests after the failure showed that the fabric was surprisingly strong. The following is an excerpt from a report of a strength test performed by the Applied Science Division of Litton Industries:

> Tensile strength tests were made using a 1"x6" piece of material and jaw travel of 0.02 inches per minute. Tear tests were run using a 2"x3" piece of material with a 2" slit parallel to the 3" dimension with jaw travel of 10 inches per minute.
>
> Our conclusion from these tests is that the cotton material was not rotten. Its strength shows up favorably although the cotton is appreciably heavier than the modern fabrics. We cannot estimate the weight of the cotton because of the buildup of paint on the surface. These tests do not indicate how the materials would compare under dynamic loading or what their permeability to gas might be.
>
> The test data were obtained on an Instron tensile testing machine used routinely by us for materials testing. However, the test methods used were one of a number of different test methods used by different companies and testing laboratories in testing these type materials. Further, we could not be certain of the detailed construction and orientation of the two-ply coated fabric in cutting our samples for test. The net result is that we believe the test results should be considered on a qualitative and not on a quantitative basis.
>
> The test results obtained are as follows:

		Tensile Strength lb/inch		Tear Strength lbs	
	Wt/sq yd	Warp	Fill	Warp	Fill
Barrage Balloon (Egyptian Cotton)	13.9 oz	84	100	5.6	5.9
Neoprene Coated Dacron (Bias ply with Hypalon paint)	8.4	52	53	4.2	1.7
Neoprene Coated Nylon (Bias ply with aluminum pigmented neoprene paint)	8.3	136	103	18.5	11.6

> It would seem that the old British balloon stood up very well with time and that failure was due to either dynamic loads or to progressive failure of the load lines.

TEST OBSERVATIONS AND CONCLUSIONS

1. Survivability.--Movement of the balloon between logging site and bedding ground in relatively low-velocity winds presented handling problems. Instability, which stopped logging in winds exceeding an estimated 15 miles per hour, was attributed to the short (500 feet) tether line.

2. Payload capability and cycle time.--Turns weighing up to 4,500 pounds were yarded with logs free of the ground, and turns weighing up to 6,100 pounds were yarded with one end of the logs in contact with the ground. Average cycle time was 6 minutes, and average turn consisted of 1.48 logs.

3. Dynamic force data.--Photographic methods to aid in determining balloon yarding forces failed to provide the desired information. Future tests should be instrumented to obtain this information.

4. Reliability.--Although balloon failure ended testing of the single-hull design, high reliability was indicated by the low requirement for unscheduled maintenance during the test.

5. Logistics.--Better procedures are necessary to avoid overfilling a ballonet-type balloon. Gas leakage, which was a problem during the first phase of testing, was corrected by painting the balloon. Scheduled maintenance of the single balloon, other than gas replenishment, was neglibible.

6. Application.--Primary application of balloon logging systems will be yarding downhill, where the logs can be pulled away from facing slopes and where the long yarding distance available with these systems can substantially reduce roadbuilding cost.

RECOMMENDED RESEARCH

The experience gained in this test and observations made of other balloon logging operations, as well as discussions with representatives of balloon manufacturers, have indicated several areas requiring engineering research to produce an optimum balloon logging system. The following are primary research areas:

1. Ammonia as inflation gas.--One of the most serious problems observed in balloon logging trials has been the cost of helium. The price of helium varies, depending on the location. In the Washington-Oregon coast area, the initial inflation gas, delivered by tank truck, costs approximately 6 cents per cubic foot, and the replenishment gas, contained in standard helium cylinders, costs approximately 10 cents per cubic foot. In less accessible areas, the price will be considerably higher. With a 100,000-cubic-foot balloon and an assumed annual leakage of 100,000 cubic feet, this represents $6,000 for initial inflation and $10,000 a year for replacement.

Another problem related to the cost of helium is the reluctance of an operator to deflate a balloon when high winds are expected. Equipment is commercially available for recompressing helium but the present expense of such equipment is prohibitive, so deflation means loss of the valuable gas. Reluctance to dump the gas can result in loss of a balloon as well as the gas.

This problem becomes minor by the use of ammonia gas to provide lift, and a thorough investigation of the feasibility of using this gas is recommended. Ammonia will provide approximately half of the buoyant force of helium, but the cost of ammonia is relatively insignificant. About $150 worth of ammonia will fill a 100,000-cubic-foot balloon. The investigation to determine the feasibility of using ammonia should include the following:

(a) Study the hazards involved in using ammonia

(b) Determine requirements for compatible materials in balloons and inflation systems used with ammonia

(c) Design a gas generation system to provide the heat necessary for quick vaporization of the ammonia

(d) Design a balloon system to provide the desired performance characteristics with ammonia as an inflation gas

(e) Test an ammonia-filled balloon yarding system

2. Dynamic analysis.--Payloads have been yarded considerably in excess of the static lift of the balloons being used. The additional lifting force is obtained from a combination of balloon inertia, aerodynamic lift, aerodynamic drag, and, in some cases, from main and haulback line tensions.[2]

The exact relationship of these various forces during log pickup, skidding, and yarding is unknown and cannot be determined without data from some fully instrumented tests. This information is necessary to perform a dynamic analysis of balloon yarding which will provide design parameters for an optimum balloon system. It is recommended that instrumented tests be performed to provide data on line tensions and balloon velocity and acceleration for an analysis.

3. Configuration studies.--Up to this test, balloons have not been designed for logging. The basic shape of a balloon will influence the performance, reliability, and survivability and may also influence the initial cost, stability, and gas consumption. It is recommended that a study of various balloon shapes be performed. Results of the dynamic analysis are necessary to perform this study.

---

[2] Mann, Charles N. Forces in balloon logging. Pacific Northwest Forest & Range Exp. Sta. U.S. Forest Serv. Res. Note PNW-28, 5 pp., illus. 1965.

Basically, a balloon consists of an envelope which contains the lifting gas. On some balloons, airfoils are provided for lift and stability. These airfoils are usually pressurized by gas, ram-air, or an airblower system. Research is necessary to determine the requirements for airfoil surfaces and to determine the best pressurization system. Consideration should also be given to the use of noninflatable high-lift and drag devices.

A dilation system is used for gas expansion and contraction, due to changes in altitude and temperature, and also to maintain an internal pressure to resist wind pressure on the hull. Three systems are in current use today, namely:

(a) Expandable tension sections

(b) Ram-air pressurized ballonet

(c) Electric-blower pressurized ballonet

Studies are needed to determine the most reliable and efficient dilation system.

4. Balloon logging carriage.--In downhill balloon logging, any load that can be lifted off the ground can be yarded into the landing. When a load is moving toward the landing, relative wind produced by the balloon motion provides dynamic lift, which, together with the static lift, supports the load. During log pickup in still air, loads in excess of the balloon static lift require an additional upward force. In this test, the additional force was produced by pulling slack in the tag line. This allowed the balloon to rise freely until the slack was removed, at which time deceleration of the balloon produced an impact load on the logs. At the same instant, the main line was accelerated to keep the logs in the air and start them into the landing.

Several problems were encountered with this type of loading. The short duration of the impact load and slack in the main line required precise timing to keep the logs in the air. Drag force limited the free rise velocity of the balloon. The noseup attitude of the balloon, which resulted from the free rise, caused unbalanced loading of the balloon suspension cables. This unbalanced loading destroyed the test balloon.

The experience gained in this test pointed out the requirement for a different method of lift-off loading, which led to a new balloon-logging-carriage concept shown in figure 8. Operation is shown in figure 9. After chokers are secured to the logs, the main line is let out, allowing the balloon to rise. When the balloon has reached the desired height, the main line is rapidly pulled in, which induces an upward pull on the logs and a downward pull on the balloon. Motion of the balloon is opposed by static lift, inertia, and drag; and these forces combine to lift the logs. A bumper fitting on the line above the tag line fixes the length of the tag line to facilitate choker setting and log landing. Design and testing is required to develop this concept.

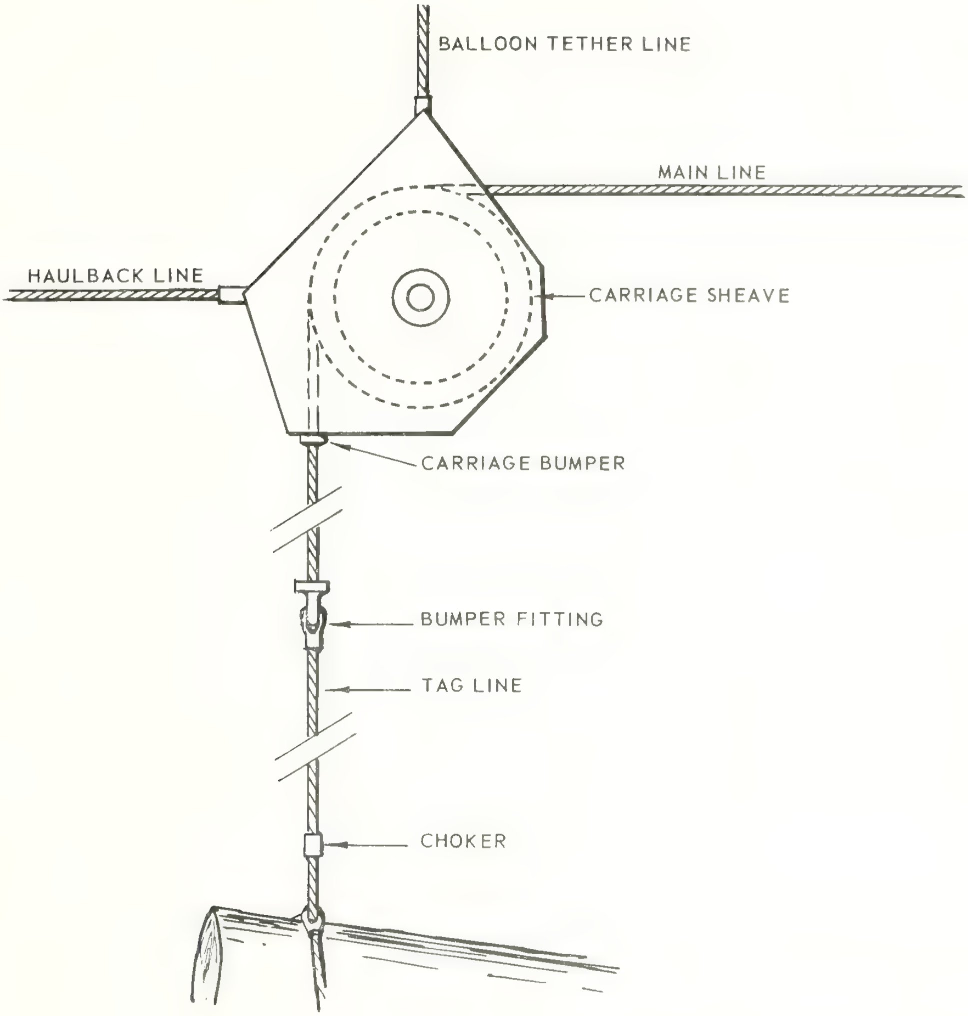


Figure 8.--Balloon logging carriage.

Secondary balloon logging research should be performed in the following areas:

1. Deicing.--Balloon logging has great potential in areas where wet snow is prevalent. However, a small amount of wet snow will overcome the static lift of the balloon. Deicing chemicals, coatings, and hull shapes should be investigated as possible solutions to this problem.

2. Personnel transportation.--Extended downhill yarding carries with it the costly problem of crew transportation. A suitable carriage or gondola should be designed for transportation of personnel. Indications are that this can be safely accomplished with the balloon.

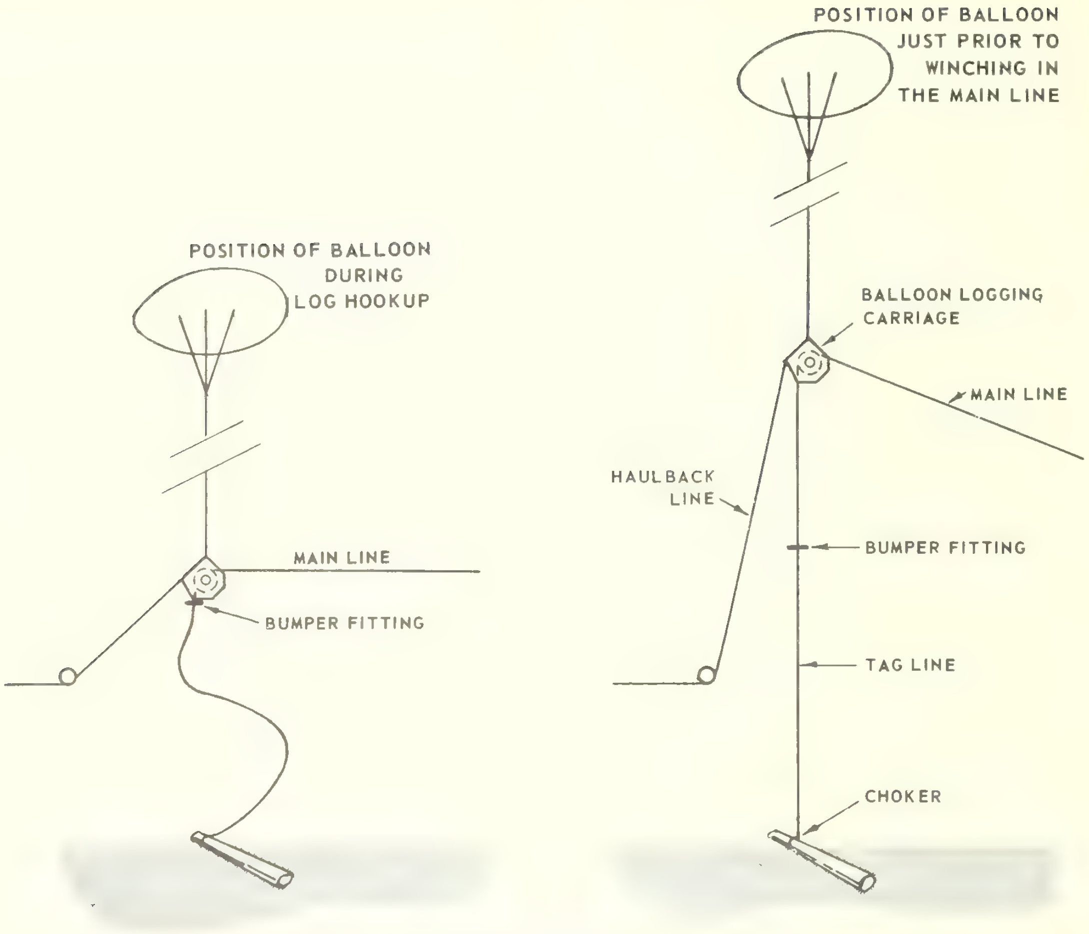


Figure 9.--Balloon logging carriage operation.

3. Ground handling and tiedown.--Previous tests have shown that balloon survivability is greatly dependent on proper ground handling and tiedown. Further studies are needed to develop suitable procedures for handling and tiedown under logging conditions.

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ECONOMIC GUIDES for

a method of
precommercial thinning of
ponderosa pine in the Northwest

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INTRODUCTION

Shown in charts in this publication are some economic aspects--costs per acre and rates of return on investment--of precommercial thinning in even-aged ponderosa pine stands.

Precommercial thinning probably absorbs more money annually than any other aspect of stand improvement. For example, in fiscal year 1965, almost 29,000 acres of predominantly ponderosa pine stands were thinned by the U.S. Forest Service in the Pacific Northwest, at an estimated cost of over $1-1/2 million. Further, the number of acres thinned is increasing (fig. 1).

During the planning of stand improvement work, such questions arise as: Other things equal, do high-cost, dense stands give more growth response per dollar spent than low-cost, open stands?

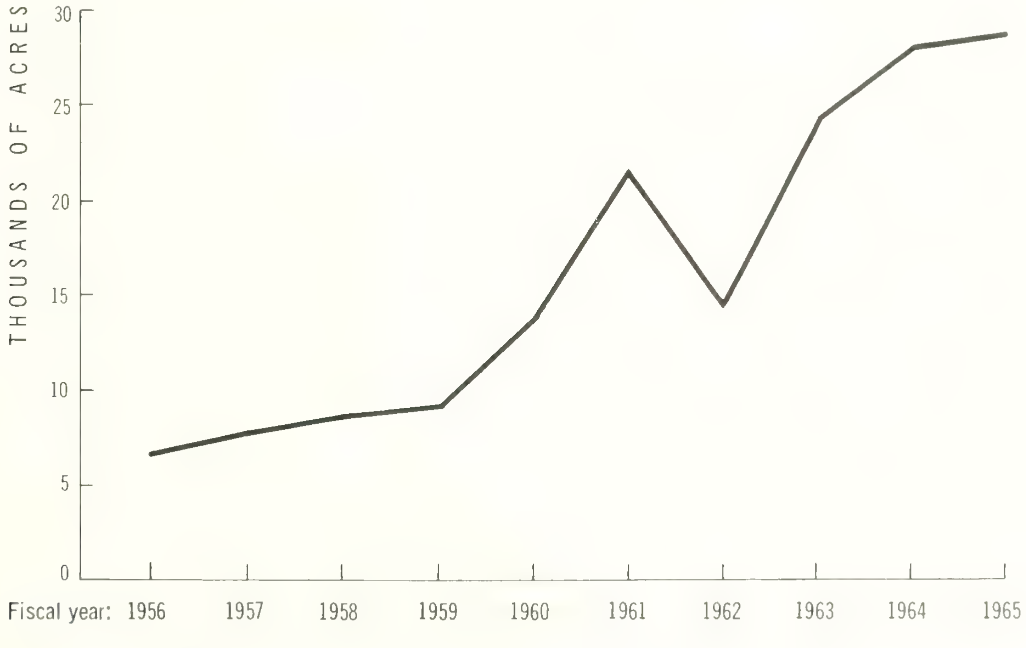

Figure 1.--Precommercial thinning by the U.S. Forest Service, Region 6, 1956-65. Source: U.S. Forest Service, Region 6. Annual planting and stand improvement report.

Should a high-site stand with dense stocking and small diameters be given priority over a low-site, open stand with larger trees? How should thinning be rated against pruning or dwarfmistletoe control? A convenient means of comparing these diverse alternatives is to rank them according to their rates of return on investment.

Because of widespread and continuing interest in ponderosa pine thinning, several economic evaluations have been made, mainly in other regions. Wikstrom and Wellner (1961) calculated rates of return for high, medium, and low sites in the northern Rocky Mountains. Their estimates assumed that returns will not be realized until the timber is cut; that is, they did not include the allowable cut effect explained later in this publication. A rate of return of slightly over 3 percent was calculated for high sites.

Mowat (1953) estimated a 2-percent rate of return on ponderosa pine precommercial thinning investments in central Oregon, based on plot remeasurement data there.

For the Southwest, Gaines and Kotok (1954) made calculations of the dollar value of shortened rotations arising from early thinning, based on numerous thinning experiments. Shortening the growing time required to reach merchantable size could, according to their figures, return more than 5 percent on the treatment cost.

DEVELOPMENT OF METHOD

The rate-of-return chart (fig. 2) and thinning-cost diagram (fig. 3) are based on data collected during a study of dwarfmistletoe control economics (Flora 1966). The dwarfmistletoe study required estimates of ponderosa pine yields from uninfected as well as infected stands, both thinned and unthinned. Also involved were field studies of thinning costs in infected and uninfected stands. Thus, an analysis of thinning economics was possible without further data collection. The calculations are discussed in the appendix.

The method of thinning studied involved one-man Forest Service crews using powered circular saws commonly termed brushcutters (fig. 4). Stocking was reduced to prescribed levels (about 350 trees per acre) under a thinning program designed to favor "crop trees" rather than a fixed spacing between leave trees.

The rate-of-return calculations include allowance for nonproductive time--breakdowns, saw sharpening, fueling, and the like. Also included is an adjustment for travel on "company" time. The cost chart, too, allows for nonproductive time, but a separate adjustment must be made for travel. Cost estimates obtained from figure 3 should be multiplied by an appropriate factor from table 1.

Costs of roadbuilding and slash reduction are not incorporated in the calculations for this report.

Figure 2 was developed for organizations whose annual cut is based on the Austrian formula or similar method of calculating the allowable cut. In such a method, the allowable cut is determined partly by anticipated increment. Thus, a decision to thin produces an immediate and continuing adjustment of the allowable cut.[1] This, in turn, requires old growth or other merchantable timber from which the additional cut can in fact be taken.

The physical effect of an allowable-cut adjustment is the movement forward of the cutting of old-growth timber. The sooner income is generated by an investment, the greater will be the rate of return on investment. Hence, a policy of even-flow management, with release of old-growth cutting units in anticipation of volume growth elsewhere, increases the apparent "profitability" of thinning over what it would be if returns from treatment could not be obtained until the thinned acres are themselves harvested.

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[1] If actual rather than anticipated increment is used, the effect on allowable cut is delayed until a forest inventory reflects the increased growth.

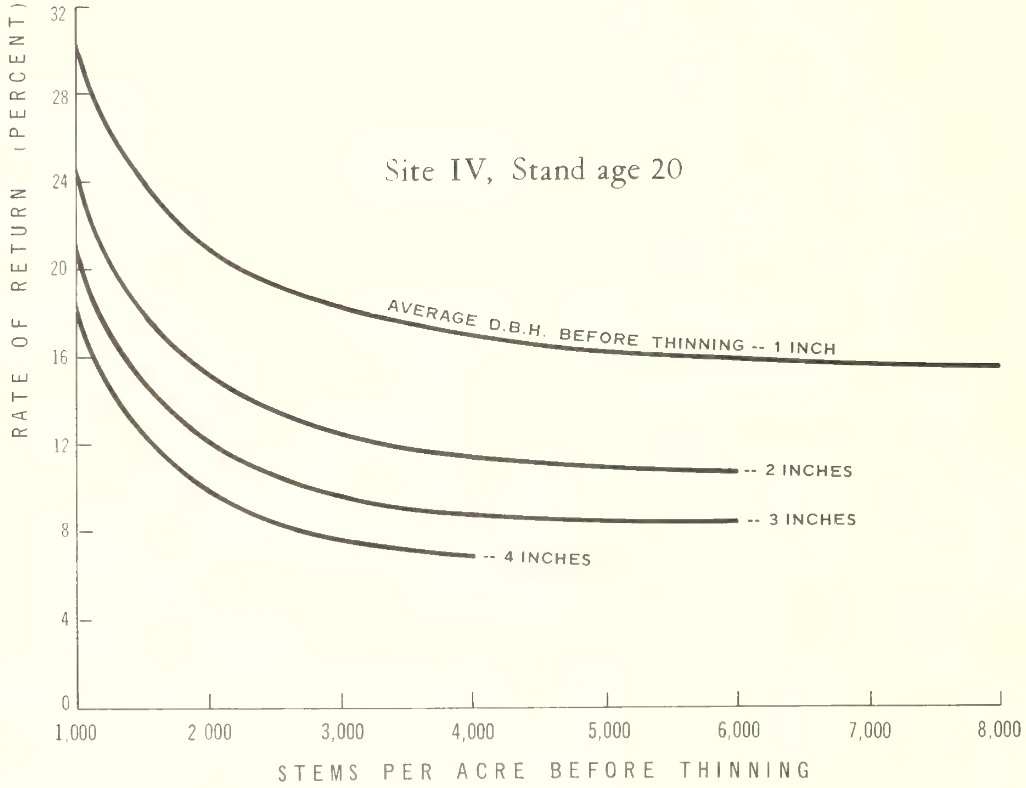

Figure 2.--Rate of return on investment, precommercial thinning, ponderosa pine. Site IV; stand age, 20 years. Rule: For each increase of site quality by one class, subtract ½ percent; for each increase of stand age by 10 years, if average d.b.h. is: 1 inch, add 2½ percent; 2 inches, add 1½ percent; over 2 inches, no adjustment.

Table 1.--Factors for adjusting costs to include travel cost[1]

Travel time during an 8-hour shift (minutes)	Distance, round trip, miles							
	10	20	30	40	50	60	70	80
15	1.052	1.071	--	--	--	--	--	--
30	1.088	1.109	1.129	1.150	--	--	--	--
45	1.125	1.148	1.170	1.192	1.214	1.236	--	--
60	--	1.191	1.215	1.239	1.262	1.286	1.310	1.334
75	--	--	1.262	1.288	1.314	1.339	1.365	1.391
90	--	--	--	1.342	1.370	1.397	1.425	1.453

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[1] Multiply estimated cost without travel by the appropriate adjustment factor. A vehicle and labor cost of 15 cents per mile is assumed.

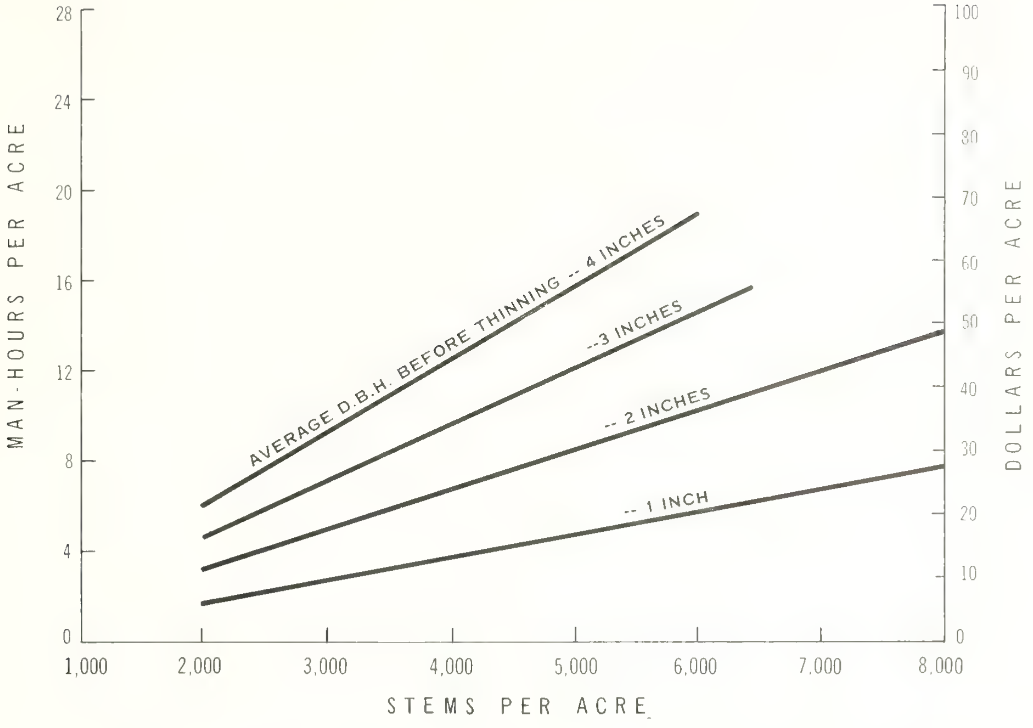
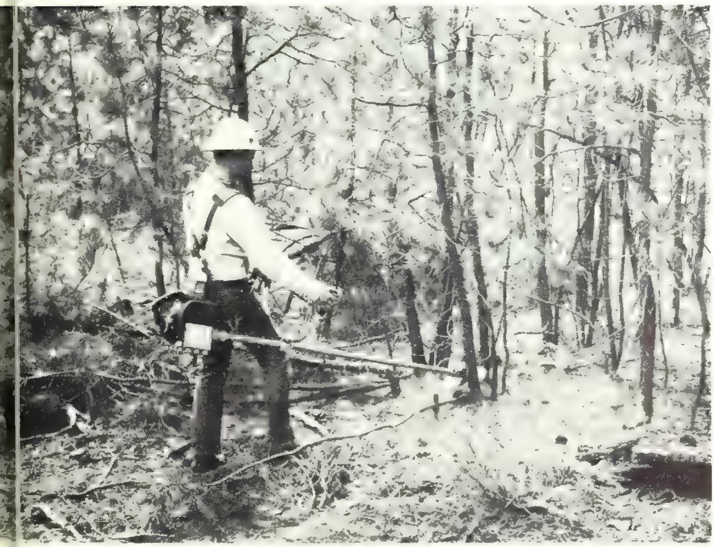


Figure 3.--Precommercial thinning of ponderosa pine, time and cost per acre.

Figure 4.--Brushcutter used in thinning young stands.



Use of the guides in this publication should be limited to areas where: (1) stands are accessible; (2) commercial timber production, on an even-flow basis, is the principal objective of stand management; and (3) assumptions outlined in the appendix are valid.

It will be noticed that the rule given in figure 2 for rates of return indicates that higher rates occur on lower sites, if other stand characteristics are equal. This circumstance, which appears unreasonable on the surface, is also discussed in the appendix.

PROCEDURE FOR USING CHARTS

GIVING STANDS PRIORITIES FOR TREATMENT

1. From type maps or field reconnaissance, estimate the following for each stand:
    - Site class
    - Stand age
    - Average d.b.h. (before thinning)
    - Stocking in stems per acre (before thinning)

2. Use figure 2 to estimate the rate of return for each stand.

3. Make a list of the stands, with columns for stand identity or location, its acreage, and its total thinning cost. List the stands in order with high rates of return at the top.

4. Using the procedure outlined below, estimate the total cost of thinning each stand. Enter this figure in the last column.

5. Choose for treatment those stands at the top of the list, working down until the figures in the total-cost column indicate that the amount of money available for thinning is nearly committed. Leave allowance for slash abatement, if required, and other contingencies.

ESTIMATING THE COST OF THINNING

1. From type maps or field reconnaissance, estimate the following for each stand:
    - Average d.b.h. (before thinning)
    - Stocking in stems per acre (before thinning)
    - Acreage of the stand
    - Round-trip distance to the stand "from town" and one-way travel time

2. Use figure 3 and table 1 to estimate thinning cost per acre.

3. Multiply thinning cost per acre by stand acreage to obtain total cost of thinning the stand.

APPENDIX

The computational background for this publication can be considered in four parts: time studies, cost analyses, growth data, and rates of return.

TIME STUDIES

In 1961, the Forest Service conducted studies of dwarfmistletoe control costs in young ponderosa pine stands in eastern Oregon. Over a hundred treatment areas, averaging 2 acres in size, were thinned. Of the compartments, 26 were free of dwarfmistletoe and were thinned according to Region 6 stand improvement guidelines to about 350 stems per acre.[2] Crop-tree thinning, rather than uniform thinning, was prescribed.

It was found that on both infected and uninfected compartments, thinning time per acre was related in linear fashion to stocking and to stocking multiplied by average d.b.h. Specifically, for uninfected stands, thinning time per acre was

$$T = -11 + 0.03416DS + 0.0122S$$

where T = Man-minutes per acre
D = Average d.b.h. before thinning
S = Stems per acre before thinning

This equation yielded a multiple correlation coefficient of 0.86. Not included are the various delays caused by equipment breakdowns, refueling, and the like, which added 30 percent on the average. Thus, the equation becomes

$$-14.6 + 0.04441DS + 0.0159S.$$

COST ANALYSES

The principal cost of precommercial thinning is, of course, labor. An average hourly labor cost of $2.38 was used, based on actual crew costs and including FICA charges, payroll overhead, and field supervision.

Brushcutters, which use a chain-saw engine to power a small circular saw, cost about 93 cents per machine hour for maintenance, repair, replacement, and fuel.

To these direct costs were added 80 cents per acre for layout of string lines to guide the thinners and for selections of treatment areas and 16 percent of direct costs to cover overhead.

GROWTH DATA

The economic merits of thinning depend on growth of thinned versus equivalent but unthinned stands. Yield estimates for unthinned stands in the Northwest were based on work by Lynch (1958). Separate projections were made of basal area per acre and stems per acre:

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[2] U.S. Forest Service. National Forest timber stand improvement handbook, Region 6. 1963.

$$\text{Log } B = 2 + (\text{Log } S - 2)(A/L) - \text{Log } (0.5663 - 0.2715H/L + 15.2858/L)$$

where $S = I(0.5663 - 0.2715H/A + 15.2858/A)$
B = Future (predicted) basal area per acre
I = Initial basal area per acre
H = Average height of dominant trees in initial stand
A = Initial stand age
L = Stand age for which basal area is being predicted.

$$\text{Log } N = 2.6078 \text{ Log } H - 11.215/L + 1.4579 \text{ Log } B + 4.1007$$

where N = Future (predicted) stocking, stems per acre.

The constant, 4.1007, was not derived by Lynch, but was estimated from other yield data.

Yield estimates for managed stands were taken from stand improvement guidelines developed by the U.S. Forest Service.[3] Adjustments were made for stands of different pretreatment stocking and average d.b.h. than those envisioned in the guidelines.

RATES OF RETURN

The economic effect of a decision to thin is defined in this publication as a change in allowable cut, beginning soon after the decision and lasting through the current rotation. Rotations were arbitrarily assumed to be 80 years for site class II, 100 years for site class III, 120 years for site class IV. However, rates of return are rather insensitive to rotation lengths.

Mean annual increment (M.A.I.) at rotation age was calculated for thinned and unthinned stands ranging in age from 20 to 40 years for site classes IV to II, average d.b.h. from 1 to 4 inches, accessibility from 10 to 40 miles' driving distance "from town," and stocking from 2,000 to 8,000 stems per acre. The difference of M.A.I. between a thinned and an unthinned stand was presumed to be the annual amount by which allowable cut was increased by a thinning decision. If, for example, M.A.I. was 350 board feet per acre per year with thinning and 250 without thinning, a gain in allowable cut of 100 board feet per acre per year was credited to thinning. If the stand was 30 years old and a rotation age of 120 years was anticipated, then the effect of thinning on allowable cut was assumed to continue for 90 years.

Gain in allowable cut was valued at $15 per thousand board feet, reflecting stumpage price experience in the recent past and the national outlook for timber supply and demand. To establish the rate of return on investment, a rate of interest was used to discount each year's allowable-cut increase. The discounted gains were summed and compared with the investment outlay involved in thinning. Different rates of interest were tried until a rate was found which made the sum of discounted gains just equal to thinning cost.

This rate of interest, or rate of return on investment, was calculated for each of several hundred stands differing as to site, average d.b.h., stocking age, and accessibility. To permit portraying so many alternative conditions, regression equations were developed, relating rate of return to identifiable stand characteristics. Figure 2 is derived from the equations. It was found that accessibility, thought to influence the profitability of thinning, does not add significantly to the precision with which rates of return can be estimated. The coefficient of determination for this equation is 0.92. The equation is:

---

[3] See footnote 2.

$$P = -8.00 - 0.0457Q + 0.348A + 0.0002DS - 0.0976DA + 8.9817(1/D) + 18{,}414(1/S)$$

where P = Rate of return on investment
Q = Site index
D = Average d.b.h. before thinning
S = Stems per acre before thinning
A = Stand age at time of thinning

In the equation, site index has a negative coefficient, indicating that as site quality increases rate of return drops. This fact, reflected in the rule of figure 2, can be explained with an example. Suppose that mean annual increment in stands on two different sites is as follows:

	High site (Bd.ft./acre)	Low site (Bd.ft./acre)
With thinning	400	350
Without thinning	300	200
Difference	100	150

In this hypothetical example, high site gives better yields than low site, with and without thinning, as would normally be expected. However, response to thinning is greater on low site, as indicated by the bottom figures. Hence, if thinning costs are the same on both sites, the lower site with its larger response offers a higher return on the thinning investment.

Because compound rates of interest are involved, rates of return are influenced most heavily by returns obtained in the near future. This fact is reflected in the stumpage values assumed. Further, it accounts for the insensitivity of rates of return to rotation decisions.

SENSITIVITY TO LABOR COSTS

Since most of the cost of stand treatment goes to labor, a change in prevailing wage rates can affect rates of return on treatment investments. In general, rate of return on treatment investment is inversely proportional to cost. Thus, if labor cost per hour increased to six-fifths of its former level, percent rate of return would become five-sixths of the previous figure.

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SUMMARY

Procedures and data used in developing estimates of costs and rates of return for three methods of dwarfmistletoe control are explained in detail. Results of the calculations have already been published as "Economic Guides for Ponderosa Pine Dwarfmistletoe Control in Young Stands of the Pacific Northwest" (Flora 1966). This explanation of methodology is intended for persons particularly interested in the simulation models employed.

INTRODUCTION

BACKGROUND AND OBJECTIVE

Interest in dwarfmistletoes and their impact on timber production in the West is not new. Cooper in 1906, Woolsey in 1911, Meinecke in 1914, Weir in 1916, and Munger in 1917 reported on western dwarfmistletoes. A considerable history of biological research on the parasites has developed, and surveys have suggested the wide extent of dwarfmistletoe infestation (Hawksworth and Lusher 1956). In the 1950's, dwarfmistletoe control techniques became generally operational.

In 1959, the Pacific Northwest Forest and Range Experiment Station undertook a study of the economics of ponderosa pine dwarfmistletoe control. The specific questions asked were: How much does dwarfmistletoe control cost under different stand conditions? Can returns from control justify the cost? If yes, what stands should receive priority for treatment?

It was soon found that treatment cost data and information obtainable on growth of infected trees were based on measurements of single trees or stands. Systematic studies across representative ranges of infection, stand size, and density had not been made. Therefore, in 1961, treatment cost studies were made on the Deschutes National Forest in eastern Oregon. Arrangements were also made to obtain interim, tentative results from dwarfmistletoe studies planned or already started by the Divisions of Forest Disease Research at the Rocky Mountain and Pacific Northwest Forest and Range Experiment Stations. By 1964, it was decided that sufficient information was available for varied combinations of stand characteristics to complete the economic study. The resulting publication was "Economic Guides for Ponderosa Pine Dwarfmistletoe Control in Young Stands of the Pacific Northwest."

This report explains in greater detail the cost data, growth information, economic values, and analytical procedure used in that publication.

THE ALTERNATIVES EXAMINED

Dwarfmistletoe control in juvenile stands is commonly accompanied by timber stand improvement measures, specifically pruning and thinning. However, this study dealt with mistletoe control alone, and the economics of silvicultural pruning are not considered here.

Precommercial thinning does enter the analysis, because precommercial thinning and dwarfmistletoe control are interdependent. That is, they are joint operations in that they occur simultaneously, one operation generally accomplishes part of the objective of the other, and costs incurred for one may reduce the cost of the other. For example, thinning usually removes some infected trees, and disease control eliminates some silviculturally undesirable stems. Interdependence of the two treatments may also be detrimental--disease control may reduce stocking below the silvicultural optimum.

Because of the relationship of thinning and disease control, four alternative treatment options were considered for infected stands:

1. Thinning only
2. Mistletoe control only
3. Mistletoe control with thinning
4. Mistletoe control in previously thinned stands

All of the options refer to juvenile stands, in which treatments are cost producing not income generating.

For each investment option, treatment cost per acre and rate of return on treatment investment were determined for several thousand combinations of stand characteristics. The following sections describe: first, how treatment costs were estimated; second, how returns from treatment were estimated and integrated with cost to establish profitability.

ESTIMATING TREATMENT COSTS

THE METHODS OF TREATMENT

Dwarfmistletoe control involved physical removal of infected branches or felling of infected trees. The procedure called for (1) removal of overstory trees as a part of the organization's timber harvest program; (2) thinning to remove understory trees with (a) stem infections, (b) limb infections close to the bole, or (c) so many branch infections as to make pruning impractical; and (3) pruning infected branches from the remaining trees. Thinning was done with powered circular saws called brushcutters; pruning was with pole saws. Overstory trees of less than merchantable size were felled with chain saws.

The specific guidelines employed in the study were:

1. Work through the mistletoe area, removing all the smaller heavily infected trees, trees with severe stem infections, and large infected trees that are definitely not savable.

2. Rework the area, starting with the largest trees, selecting uninfected or infected prunable trees to leave. Decrease tree size classes until proper number of leave trees are found.

3. Remove all remaining infected or noninfected trees to the desired spacing.

. . . try to retain a minimum of at least 150 uninfected leave trees per acre in heavily infected stands.

When a definite hole 35 to 40 feet in diameter or larger occurs because there are no uninfected or prunable infected trees that can be left, or when spacing begins to exceed an average of 16 feet, trees of 2 inches d.b.h. or over and having not more than two infections in the lower one-third of the bole may be left, provided there are no uninfected 1-inch d.b.h. class or smaller leave trees within 25 feet.

Cut all infected but vigorous crop trees, even if only one or two mistletoe infections occur above prunable height. However, if cutting a tree leaves a nonstocked

opening, the tree can be left if plans are made to remove the infected branch by other than normal pruning procedures. In this study, it will be considered better to leave a small, nonstocked opening than to leave a tree with infection high in the crown.

Thin and prune to remove all visible mistletoe infection. Retain about 50 percent more than normal stocking if possible. (For example, if normal stocking for site IV[1] is 355 leave trees per acre at an average spacing of 11 feet by 11 feet, 50 percent more would bring the number of leave trees per acre up to 533 at 9 feet by 9 feet average spacing.) This will provide for subsequent rethinning at periodic intervals, or until mistletoe is controlled.

Remove all trees with infections in, or within 4 inches of, the bole and all trees from which infection cannot feasibly be pruned (normally above 20 feet). Thin and prune uninfected portions of the stand according to normal procedures and stocking.[2]

The guidelines were prepared by National Forest staff personnel to conform to general field practice in the Northwest.

It was also necessary to estimate the cost of precommercial thinning without attention to dwarfmistletoe control. Precommercial thinning was also done with brushcutters, using a crop-tree, rather than a uniform, thinning philosophy. Crop-tree thinning emphasizes selection of desirable dominants or codominants for leave trees, sacrificing uniformity of spacing if necessary.

A stocking objective of 355 stems per acre was employed for precommercial thinning. In infected stands, 50 percent more stems were left to allow for stocking reduction in subsequent recleanings.

DATA COLLECTION

Field research on treatment costs was based on time studies of experienced crews. Seventy-seven compartments, averaging 2 acres in size, were established in infected stands on the Deschutes National Forest. An additional 12 compartments were placed in uninfected stands. Stand characteristics were measured with a grid of 1/250-acre plots spaced 1 chain apart. A broad range of stand characteristics was involved:

Average d.b.h., 1 to 4 inches
Stems per acre, 400 to 10,000
Percent of stems infected, 0 to 92

Stopwatch studies were made under generally favorable weather conditions. Work was suspended in cloudy weather because of difficulty in seeing mistletoe plants at such times. As in operational work, string lines were run at 2-chain intervals to guide the crewmen. Two men, accompanied by a timekeeper, worked in each 2-chain-wide strip. As in normal practice, 2 foremen and a saw maintenance man were employed for each 10-man crew. For each crew, two "carry-all" enclosed vehicles and a pickup were generally used. Fifteen thinning saws were kept available for a 10-man crew to minimize breakdown delays. When pruning infected trees, each man had one 7-foot and one 14-foot pruning saw.

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[1] U.S. Forest Service. National Forest timber stand improvement handbook, Region 6. 1963.

[2] Dykeman, K., and Simonson, J. Project work plan for study of dwarfmistletoe control costs. 12 pp. 1961. (On file at Deschutes National Forest, U.S. Forest Service, Bend, Oregon.)

Delay and work times were subdivided according to the activities from which they arose. Timekeepers recorded the effort devoted to each compartment to the nearest man-minute.

DWARFMISTLETOE CONTROL WITH THINNING

Regression analysis was used to relate the per-acre time and cost of treatment to stand characteristics. Dwarfmistletoe control with precommercial thinning requires separate felling and pruning operations.

Felling.--An equation for predicting man-hour requirements for the felling portion of treatment was based on 77 compartments:

$$\text{Man-hours per acre} = 1 + 0.00133DS$$

$$R \text{ (correlation coefficient)} = 0.95$$

where D is average d.b.h. before treatment, and S is stems per acre before treatment.

Reduction of residual variance attributable to addition of a variable measuring the level of dwarfmistletoe infection was nonsignificant at the 5-percent confidence level. The relative unimportance of the infection variable (after stand density and tree size are used) can perhaps be attributed to the fact that once the stand is known to be infected, each tree must be searched visually for mistletoe plants. Scanning time is probably directly related to tree size and the number of trees per acre. Both of these factors are already in the equation. The influence of infection intensity on felling time per acre may be slight, at least in stands whose density is such that at least as many trees as are infected must be cut anyway for silvicultural reasons.

Pruning.--For pruning, the comparable equation is:

$$\text{Man-hours per acre} = 2.58 + 0.01495DM$$

$$R = 0.97$$

where M is number of stems pruned per acre.

Experience on the infected compartments led to an equation for predicting the number of stems pruned per acre for mistletoe:

$$\text{Stems pruned per acre} = 25 + 0.0746I - 0.0000125I^2$$

$$R = 0.76$$

where I is the total number of stems per acre that are infected before treatment.

DWARFMISTLETOE CONTROL ONLY

For dwarfmistletoe control without precommercial thinning, pruning operations require as much effort as for control with precommercial thinning; hence, there is no change in the man-hour equation for pruning. However, a revised felling equation is necessary because only infected trees are felled. An estimate of time saved by leaving uninfected stems was obtained from an equation developed for thinning uninfected stands, whose derivation is described elsewhere

(Flora 1966). The latter equation is:

$$\text{Man-hours per acre} = -0.183 + 0.000203S + 0.000569SD$$

where S = total stems per acre before treatment; D = average d.b.h. before treatment. The derivative of this equation with respect to S gives an estimate of work time per uninfected tree. Thus, the derivative $(0.000203 + 0.000569D)$, multiplied by the difference between total stems and infected stems per acre, can be subtracted from the man-hour equation for control with precommercial thinning to obtain an equation for control without precommercial thinning. The resulting equation, using the previous notation and letting I = number of infected stems per acre, is:

$$\text{Man-hours per acre} = 1 - 0.000203S + 0.000203I + 0.00076SD + 0.00057DI$$

All of the man-hour equations include an upward adjustment for operational delays such as fueling and breakdowns. It was found that, on the average, an additional 30 percent of work time must be added for delay time in thinning operations and 18 percent in pruning operations.

UNIT COSTS AND COST EQUATIONS

Each of the foregoing man-hours-per-acre equations has a companion cost-per-acre equation. An average hourly labor cost of $2.38 was used, based on actual crew costs including FICA charges, payroll overhead, and field supervision. The powered thinning saws cost about 93 cents per machine-hour for maintenance, repair, replacement, and fuel. Pruning saws cost about 6 cents per man-hour of use.

The cost-per-acre equations are:

Dwarfmistletoe control with precommercial thinning--

$$\text{Thinning portion, \$/acre} = 5.21 + 0.00608DS$$

$$\text{Pruning portion, \$/acre} = 8.90 + 0.0497DM$$

where M is stems pruned per acre.

Dwarfmistletoe control without precommercial thinning--

$$\text{Thinning portion, \$/acre} = 5.28 - 0.000912S + 0.000912I + 0.002212DS + 0.00260DI$$

$$\text{Pruning portion, \$/acre} = 8.90 + 0.0497DM$$

TRAVEL COST

Of costs that cannot be attributed directly to crewmen's efforts, travel is the largest. Travel cost includes both vehicle and labor costs while crewmen travel on ''company'' time. A table of adjustment factors for travel cost was prepared (table 1), using a vehicle cost of 15 cents per mile for each of two vehicles assigned to a 10-man crew. A third vehicle was included in overhead supervision cost.

Table 1 assumes that crewmen travel in one direction, to or from the job, on their personal time but that vehicle costs in both directions are charged to the project.

Table 1.--Factors for adjusting dwarfmistletoe control costs to include travel cost[1]

Travel time during an 8-hour shift (minutes)	Distance, round trip, miles							
	10	20	30	40	50	60	70	80
15	1.052	1.071	--	--	--	--	--	--
30	1.088	1.109	1.129	1.150	--	--	--	--
45	1.125	1.148	1.170	1.192	1.214	1.236	--	--
60	--	1.191	1.215	1.239	1.262	1.286	1.310	1.334
75	--	--	1.262	1.288	1.314	1.339	1.365	1.391
90	--	--	--	1.342	1.370	1.397	1.425	1.453

[1] Multiply estimated cost without travel by the appropriate adjustment factor. A vehicle and labor cost of 15 cents per mile is assumed.

ESTIMATING TREATMENT PROFITABILITY

Treatment cost per acre alone is not adequate for giving stands priorities for improvement work, because treatments of equal cost on different stands may produce different value-growth response. Thus, it is necessary to forecast growth and value yield attributable to treatment and relate these to treatment cost in terms of rate of return on investment. These elements--yield with and without treatment and calculation of rate of return--are described below.

BEHAVIOR OF DWARFMISTLETOE-INFECTED STANDS

Investigations by T. W. Childs and James Edgren of the Pacific Northwest Forest and Range Experiment Station are the basis of this section. The relationships employed here are tentative and as yet unpublished.

Over a period of several years, they made detailed measurements of 2,097 trees on plots within the Winema (formerly portions of the Deschutes and Fremont) National Forest in eastern Oregon. Their data were used to relate d.b.h. (in the absence of treatment) to various silvicultural and pathologic factors:

$$\begin{aligned} D = {} & 110.25 - 35.97Q + 0.119A \\ & + 0.024G + 4.147Q^2 - 0.129G^2 \\ & - 0.028QA + 0.109QG + 0.001AG \\ & - 85.07 (\text{Log } Q) + 36.49 (\text{Log } A) \\ & - 196.6/Q + 507.4/A \end{aligned}$$

where Q is site class,[3] A is age, G is infection class,[4] and R (correlation coefficient) = 0.69.

All the coefficients of this lengthy equation are significant at the 95-percent level.

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[3] Meyer's site classes (1938) were used.

[4] Infection level is classified according to a rating system described in U.S. Dep. Agr. Tech. Bull. 1246, p. 77 (Hawksworth 1961). 0 represents no infection and 6.0 indicates maximum severity.

Equations for predicting total tree height were based on the same data source and were developed separately for different levels of attained infection:

Infection classes	Equation	R	N
1-2	$H = 93.28 \text{ Log } (D - 3.0) - 15.4$	0.92	176
3-4	$H = 81.22 \text{ Log } (D - 4.0) + 0.9$	0.93	99
5-6	$H = 82.40 \text{ Log } (D - 3.0) - 10.2$	0.88	93

where H is total height, D is d.b.h., and N is number of observations.

Covariance analysis showed these equations give significantly different estimates at the 95-percent level.

From the above-mentioned height and diameter estimates, individual tree volumes can be estimated from an appropriate volume table. For this purpose, an equation was derived from a Scribner volume table developed by Meyer (1938, table 34). The equation is:

$$V/D = 0.53 - 0.276D - 0.094H + 0.0179DH$$

where V is board-foot volume, Scribner rule, D is d.b.h., and H is total height in feet.

R for this equation is 0.9996; however, it should be noted that in this case, where data are based on curves, R has meaning only as a measure of closeness of fit.

The effect of dwarfmistletoe on stocking is much more difficult to estimate. On the basis of Childs' findings in eastern Oregon, ratios were obtained relating periodic mortality in infected stands of various infection levels to periodic mortality in otherwise comparable but uninfected stands. The ratios were placed in continuous form by the function:

$$\text{Log ratio} = -0.13653 + 0.20841G$$

where G is average infection class.

It was necessary to relate infection class to tenure of infection. Field observations suggest that, in the Northwest, average infection class moves from about 1.5 to about 5.5 in approximately 70 years. Transect studies in Colorado[5] showed infection class to be linearly related to time infected. If it is assumed that linearity holds in the Northwest as well, it follows that

$$G = 0.06T$$

where G is average infection class and T is number of years infected.[6]

In Colorado, it was also observed that

$$G = \frac{3P}{450 - 4P}$$

where G is average infection class within a plot and P is percentage of trees infected (expressed as a whole number). Acceptance of this observation for the Northwest seemed reasonable.

BEHAVIOR OF UNINFECTED STANDS

The above-mentioned mortality ratio requires a stocking estimate against which to apply the ratio. Lynch (1958) used data collected in the Inland Empire to devise equations for predicting stocking trends in natural, unthinned, and uninfected stands:

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[5] Results of this work, conducted by Hawksworth of the Rocky Mountain Forest & Range Experiment Station, have not been published. Similar work on lodgepole pine has been reported (Hawksworth and Hinds 1964).

[6] The comparable relationship found by Hawksworth is $G = 0.08T$.

$$W = b\left[0.5663 - 0.2715(h/a) + 15.2858(1/a)\right]$$

$$\text{Log } Z = 2 + (\text{Log } W - 2)(a/a^*)$$

$$E = 0.5663 - 0.2715(H/a^*) + 15.2858(1/a^*)$$

$$B = Z/E$$

$$\text{Log } S' = -2.6078\text{Log } H - 11.215(1/a^*) + 1.4579\text{Log } B + 4.1007$$

where W, Z, E = stocking factors used in the subsequent function,

b = basal area per acre at some initial age a (square feet),
B = basal area per acre at a subsequent age a^* (square feet),
S' = number of stems per acre at age a^*,
h = average height (feet) of dominant trees at age a, and
H = average height (feet) of dominant trees at age a^*.

Values for h, H, and the constant, 4.1007, were based on Meyer's yield table (1938).

Introduction of two more functions, one to predict total height of the average tree[7] and the other to compute volume per tree, permits determination of merchantable volume per acre. The latter has been described earlier. The former is:

$$H = -25 + 4.29D - 0.0595D^2 + 0.414Q' + 0.00186A^2 + 0.00672DA$$

where H' = total height (feet) of average tree, Q' = site index, and other notation is as before. This function was fitted to height curves in Meyer's yield table (1938, *p. 48*). Its high correlation coefficient of 0.986 indicates closeness of fit, not statistical reliability.

STAND PROJECTIONS

The foregoing growth relationships were employed together to forecast or simulate the growth of numerous hypothetical, but representative, timber stands varying as to dwarfmistletoe infection intensity at time of treatment (if any); stand age, stocking, and average d.b.h. at time of treatment; and site quality. Yield predictions were made for each of six stand conditions:

1. No dwarfmistletoe, no silvicultural thinning
2. Dwarfmistletoe infection, no control, no silvicultural thinning
3. Dwarfmistletoe control without silvicultural thinning
4. No dwarfmistletoe, silvicultural thinning
5. Dwarfmistletoe infection, no control, silvicultural thinning
6. Dwarfmistletoe control with silvicultural thinning

This height function is for uninfected trees only; the height formulas given earlier are only for infected trees.

STAND PROJECTIONS--
NO SILVICULTURAL THINNING

No dwarfmistletoe.--Suppose, for example, we have a 1-acre 30-year-old stand on site IV, with an average d.b.h. of 2 inches and 4,000 stems per acre. It is assumed that the tree of average basal area is also 2 inches in diameter, so that basal area per acre at age 30 is $2^2 \times 0.005454 \times 2{,}000 = 87$ square feet. Assume, further, an average height of dominants of 30 feet. If this stand is uninfected, the functions above support a prediction that 90 years later at age 120, there will be about 173 square feet of basal area and 168 stems per acre. Thus, basal area per tree would be 1.03 square feet, suggesting an average d.b.h. of about 13.5 inches. Volume per acre would be about 23,500 board feet.

Dwarfmistletoe infection, no control.--If this stand has been infected with dwarfmistletoe with, say, an average infection class of 1.0 at age 30, it would be possible to follow growth on a hypothetical basis. At age 40, average d.b.h. would be 4.2 inches, and there would be about 400 stems per acre. If no sanitation or other stand improvement measures were undertaken in the interim, by age 120 average infection class would increase to almost 6, and there would be only a few trees per acre, of low merchantability, with an average d.b.h. of about 12 inches. During the 80-year interval, infection would also have spread outward, causing growth reduction and increasing mortality in adjacent stands. The amount of impact depends on length of time infected and thus on distance from initial infection zone, with the more distant trees affected least. Because of this varying impact across the invaded area, average impact per acre is difficult to compute. Average impact can be approximated by computing average time infected, assuming a circular initial infection zone and a constant rate of spread in all directions. In the example above, average time infected in the area invaded during the rotation would be 47 years,[8] although time infected in the initial source acre would be about 102 years.

Dwarfmistletoe control.--If control of dwarfmistletoe were undertaken at age 30, without concurrent silvicultural thinning but with followup recleanings, it can be assumed that the sanitized stand would behave growthwise like a similar but uninfected stand. However, fewer stems would remain per acre, and their average d.b.h. would tend to be smaller, because dwarfmistletoe is more apt to be found on dominants than on smaller trees. Assume that sanitation causes a 25-percent reduction in average d.b.h., as occurred on the time-study areas, and that the number of trees felled is close to the number of infected trees observed during precleaning reconnaissance. Then, in the example, volume per acre at rotation age would be about 20,000 board feet, with d.b.h. averaging about 15 inches.

STAND PROJECTIONS--
SILVICULTURAL THINNING ASSUMED

Thus far, three alternative stand conditions have been discussed, none

[8] It can be shown that mean time infected is

[illegible]

where $k = \sqrt{43{,}560I/\pi}$

I = area of initial infection zone in acres

T = time (years) initial infection zone has been infected

L = time span (years) during which infection extends beyond initial infection zone.

involving silvicultural stand improvement; e.g., precommercial thinning. The three conditions were: no dwarfmistletoe infection, infection without control, and infection followed by control. The same three conditions could also be found in a stand receiving precommercial thinning.

No dwarfmistletoe.--To help forecast yields under these conditions, basic yield estimates for uninfected, thinned stands have been developed by the Forest Service.[9] Because some of the estimates were prepared specifically for this study, relevant portions are listed in table 2. The yield forecasts assume that stocking will be reduced by thinning to the levels

Table 2.--Abstract of assumed thinning schedules and yield estimates for uninfected ponderosa pine (Basis: 1 acre)

Site class	Average growth rate	Age class	Cut			Leave		
			Average d.b.h.	Stems[1]	Volume	Average d.b.h.	Stems[1]	Volume
	Rings per inch	Years	Inches	Number	M bd. ft.	Inches	Number	M bd.ft.
II	8	Up to 40	--	--	--	2-5	435	--
		60	7	145	--	10	290	5
		80	11	120	9-1/2	15	130	23-1/2
		100	18	130	49	--	--	--
III	10	Up to 40	--	--	--	2-6	435	--
		60	7	165	--	10	275	--
		80	11	145	9	14	130	16
		100	17	130	27	--	--	--
IV	12	Up to 40	--	--	--	2-5	355	--
		60	--	--	--	8	355	--
		80	9	175	--	12	180	9
		100	13	85	9	15	95	13
		120	16	95	23	--	--	--

[1] For convenience here, estimated mortality is included with cut.

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[9] U.S. Forest Service. National Forest timber stand improvement handbook, Region 6. 1963.

indicated for age class 40. These levels have become standard on National Forests in the Pacific Northwest.

Dwarfmistletoe infection, no control. --Yield predictions for infected stands thinned without regard for dwarfmistletoe, or for stands infected after thinning, may seem irrelevant since standard field practice involves sanitation and silvicultural thinning simultaneously. However, it is not impossible that thinning might be economic in infected stands where the considerable additional effort of sanitation may not be worth while. In any case, some infected stands are in fact thinned without dwarfmistletoe control. Further, separation of the two functions for economic analysis can aid in attributing costs separately to stand improvement and pest control budgets.

In the hypothetical stand discussed above, thinned and mistletoe-infected, diameter estimates for uninfected stands must be adjusted downward. This was done by applying a ratio of mean d.b.h. in infected v. uninfected stands, based on the Childs-Edgren diameter relation cited earlier. A similar, varying adjustment was applied to volume yields. It is assumed that dwarfmistletoe-caused mortality would be captured; hence, no stocking impact would be involved. For the example, thinning yield available at age 120 would be about 4,400 board feet instead of 23,000, as shown in the table for site IV.

Dwarfmistletoe control. --Yield forecasts can also be made for thinned stands that are concurrently treated for dwarfmistletoe. Because sanitation affects residual mean diameter and volume, table 2 values were arbitrarily reduced 15 and 25 percent, respectively.

TREATMENT OPTIONS

The six stand-condition simulations permit economic evaluation of the four stand-treatment options listed in the "Introduction." The economic advantage of each option depends on comparing the treatment cost and value yield of two stand conditions. For example, the benefit from thinning with dwarfmistletoe control is the difference in value yield of a treated stand and an infected stand without treatment. The four options and the stand-condition yields compared, all involving infected stands, are:

This option[10]	Compares this condition	With this
Silvicultural thinning only	Thinned, no sanitation	Unthinned, no sanitation
Sanitation only	Sanitation, unthinned	Unthinned, no sanitation
Sanitation with thinning	Thinned, sanitation	Unthinned, no sanitation
Sanitation after thinning	Thinned, sanitation	Thinned, no sanitation

RATES OF RETURN ON INVESTMENT

Each of the four investment options was evaluated in terms of rate of return on investment for up to 2,000 combinations of various stand characteristics. Treatment cost has been discussed; the pruning-felling method of control was assumed for dwarfmistletoe control options because of the prevalence of this method in the Northwest. Returns from treatment are the value yields discussed in the preceding section. An average stumpage value of $15 per thousand board feet was assumed. This value is, of course, arbitrary and subject to variation from place to place. Stumpage price experience in the past and the national outlook for timber supply and demand (U.S. Forest Service 1965) were weighed in choosing this figure.

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[10] "Thinning" means silvicultural thinning as distinct from felling for sanitation reasons.

Calculations of rate of return on investment were oriented to holdings on which annual cutting plans are influenced by long-term growth and mortality forecasts. Most common methods of allowable cut calculation are of this sort. Thus, if it is expected that a dwarfmistletoe control operation will forestall a given annual mortality loss, the amount of growth saved by the operation can be credited to the allowable cut immediately, even if the treated stand is not merchantable itself. Of course, there must be sufficient merchantable timber elsewhere within the management unit in order for the increase in allowable cut to be realized. Such is generally the case on industrial and public forests in the Pacific Northwest.

Returning to the hypothetical stand used earlier, suppose that dwarfmistletoe control without silvicultural thinning is contemplated. The effect of treatment is to increase ultimate harvest yield by almost 20,000 board feet per acre, or 222 board feet per acre per year during the balance of the current rotation. If it is assumed that this increase will be reflected in the allowable cut, with additional trees harvested from merchantable stands having a net stumpage value of $15 per thousand, the rate of return on treatment investment can be found by finding p in the following annuity formula:

$$\frac{C}{a} = \frac{(1+p)^n - 1}{p(1+p)^n}$$

where C = treatment cost per acre ($42 per acre)[11]

a = mean annual value yield per acre per year ($15 x 0.222 = $3.33)

n = number of years remaining in the rotation (120 - 30 = 90)

p = rate of return on investment

In the example, p is found to be about 0.08, or 8 percent. Thus, in this stand (ignoring for simplicity the benefits arising from protection of adjacent uninfected areas), dwarfmistletoe control without other treatment can be expected to return 8 percent on the control investment.

Similar calculations were made for each treatment option for many different combinations of stand characteristics. Some stand attributes were found not to influence investment profitability significantly. Surprisingly, degree of dwarfmistletoe infection was one of these. Apparently, the slight importance of infection level arises from the large proportion of control time devoted to visual search for dwarfmistletoe plants relative to actual felling or pruning time. In an infected stand, every tree must be searched whether infected or not.

PRESENTATION FORMAT

For the stand characteristics that do aid in predicting rate of return, the effect of variation in any single stand attribute is apt to be in a regular pattern. Thus, if several stands differing only in, say, stocking, are treated, and if their densities are 1,000, 2,000, 3,000, and 4,000 stems per acre, rates of return on treatment costs might be 4, 6, 8, and 9 percent, respectively, varying always in the same direction. Erratic values like 4, 6, 3, 5, moving up, down, up, respectively, do not occur. Because of such regularity, it is easy to portray rates of return graphically, just as was done with treatment costs. Many columns of numbers can be conveniently presented on a single graph, and interpolation is made simpler.

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[11] From Flora (1966), figures 5 and 6.

To facilitate graphing, equations were fitted to relate rate of return to stand characteristics. Of the four treatment options listed earlier, it was found that the first, silvicultural thinning of dwarfmistletoe-infected stands without concurrent control measures, is not economic. That is, no set of stand characteristics was found for which the rate of return on treatment investment approached 3 percent, the rate considered here to be the minimum return acceptable to forest managers. Equations for the other three options, all involving young dwarfmistletoe-infected stands, are:

Dwarfmistletoe control without silvicultural thinning:

$$\begin{aligned} p = {} & 11.35 + 0.0313Q' - 0.0008S \\ & - 0.2287A + 8.3649(1/A) \\ & + 1.1446D + 0.8553(1/D) \\ & - 0.1834U + 3.1677(1/U) \\ & - 0.0071DU \end{aligned}$$

Dwarfmistletoe control with silvicultural thinning:

$$\begin{aligned} p = {} & 16.91 - 0.0505Q' - 0.9557D \\ & - 0.0016S + 1820(1/S) \\ & - 0.2068U \end{aligned}$$

Control after commitment to silvicultural thinning:

$$\begin{aligned} p = {} & 21.0 - 0.2000Q' - 0.049A \\ & - 0.0305D^2 - 0.0002DS \end{aligned}$$

where p = rate of return on investment (percent)

Q' = site index

S = stocking before treatment (stems per acre)

A = stand age

D = mean d.b.h. before treatment

U = size of infected area (acres)

SENSITIVITY TO LABOR COSTS

Since most of the cost of stand treatment goes to labor, a change in prevailing wage rates can affect rates of return on treatment investments. Costs in this analysis are based on hourly wage rates of about \$2.05 for crewmen and a salary of about \$5,000 per year for foremen. An additional allowance was added for payroll overhead--employer's contribution to FICA, health, and retirement plans. An average cost per man-hour, including payroll overhead and supervision, of \$2.38 was assumed.

In general, rate of return on treatment investment is inversely proportional to cost. Thus, if labor cost per hour increased to six-fifths of its former level, percent rate of return would become five-sixths of its previous figure.

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Differential effects of the [illegible] OUTBREAK in Eastern Oregon

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BY CARROLL B. WILLIAMS, JR.

PACIFIC NORTHWEST
FOREST AND RANGE EXPERIMENT STATION
U.S. DEPARTMENT OF AGRICULTURE

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INTRODUCTION

Differential effects of defoliating insects on forest trees are often observed but seldom recorded in a systematic way. The most noticeable differences are usually associated with tree species. This may or may not be the result of larger populations of feeding insects concentrated on these tree species. The population growth of many insect species and the development of individual insects are usually closely synchronized with the development of a particular plant host. This plant host is usually the one most susceptible to attack and subsequent injury.

The spruce budworm (*Choristoneura fumiferana* (Clem.)) is one of the most important defoliating insect species in Western forests. In these forests, the insect causes the greatest amount of damage to true firs (*Abies* spp.), Douglas-fir (*Pseudotsuga menziesii* (Mirb.) Franco), and Engelmann spruce (*Picea engelmannii* Parry). A different form of the budworm from the one that damages forests with the above species has been reported damaging forests of ponderosa pine (*Pinus ponderosa* Laws.) and lodgepole pine (*Pinus contorta* Dougl.) (Graham 1952, *p. 200*; Mather 1932).[1]

The larval feeding period commences in spring and ends in midsummer. Larvae issuing from hibernation often mine needles, but the subsequent attack on opening buds and new growth causes the major feeding damage. Once the current year's needles and staminate flowers are destroyed, larvae will feed on older needles.

The general effect of large larval populations is severe defoliation, reduction of the normal vegetative bud complement, topkilling, reduction of annual increment, and, if continued for several years, tree mortality.

This study was made to determine the differences among grand fir (*Abies grandis* (Dougl.) Lindl.), Douglas-fir, and Engelmann spruce tree species in susceptibility to damage by the spruce budworm and, concomitantly, the impact of this damage on the respective competitive abilities of the several host tree species.

Study Areas

The study was conducted in 1958 and 1959 in four forest stands in the Wallowa National Forest of Wallowa County, Oregon, which had been recently heavily infested by budworms for 8 to 12 years. These stands were the primary infestation centers within the National Forest for the 1944 to 1956 spruce budworm outbreak. This outbreak was not chemically controlled, but by 1956 the budworm populations were no longer causing severe defoliation.

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[1] Names and dates in parentheses refer to Literature Cited, p. 16.

The Wallowa National Forest is wholly in Wallowa County, in the northeastern corner of Oregon. About 55 percent of Wallowa County is forest land, 80 percent of which is classified as commercial. Of this, ponderosa pine comprises 40 percent; Douglas-fir, 28 percent; grand fir-spruce, 17 percent; with western larch (*Larix occidentalis* Nutt.), lodgepole pine, and other species making up the other 15 percent (Bones and Schimel 1960). These tree species are encountered in the Wallowa Mountains in forest stands of several distinctive ecological types.

Grasses and islands of ponderosa pine grow on the basalt soils of the dry lowlands and on the southwestern slopes of the foothills, gradually grading into open stands of ponderosa pine, western larch, and Douglas-fir in areas of more moisture. At the higher elevations following an increasing moisture gradient, the latter species are encountered in mixed stands with grand fir, lodgepole pine, and Engelmann spruce. Spruce and subalpine fir(*Abies lasiocarpa* (Hook.) Nutt.) are abundant near timberline and along banks of streams. Grand fir, subalpine fir, Douglas-fir, and Engelmann spruce make up a large percentage of stands in the principal areas of budworm infestations.

METHODS

In 1958, 2 years after the spruce budworm outbreak had subsided, grand fir, Engelmann spruce, and Douglas-fir trees in the budworm-attacked stands exhibited wide variations in external damage symptoms. These damage symptoms were placed into various groupings to form four damage classes--light, moderate, heavy, and severe intensities of damage--and subsequently were shown to be directly related to the increment reductions occurring in trees exhibiting the symptoms. Radial increment was more responsive than height or volume increment to the various intensities of budworm feeding, supported the greatest number of damage classes, and provided the sharpest delineation among the damage classes.[2/]

Since this study reports the effects of budworm feeding on growth of tree species that appear to be competing for space and nutrients, some description of this competitive appearance is in order. If the branches of adjacent trees were intertwined or nearly touching and if the growth of one tree appeared to

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[2/] Williams, Carroll B., Jr. The impact of defoliation by the spruce budworm on the growth, specific gravity, and competitive abilities of three tree species in northeastern Oregon. Ph. D. thesis on file Univ. of Michigan library, Ann Arbor, Mich. 213 pp., illus. 1963.

be affecting the growth of its adjacent neighbors, these trees were judged to be in competition and were felled for study. Hereafter in the text, each group of apparently competing trees will be termed a competitive situation. Eleven competitive situations were examined in the study. However, to reduce repetition, the analyses of only eight are presented here.

Each tree in the eight competitive situations was rated by damage class and its diameter at 4.5 feet (d.b.h.) measured. The tree was felled, and six disks were cut at specific internodes along the stem: four were within the crown at the 1951, 1947, 1937, and 1927 internodes; one from the approximate base of the crown; and the sixth from the stump level. Total height, annual height increment (1941-58), and length of dead tops were measured on each felled tree and the number of annual rings were counted on the stump. Descriptions of the study trees and a summarization of their total height data are presented as case histories in table 1. Height increments were also graphically compared within each competitive situation (figs. 1 to 8).

Radial increment was obtained from the disks by measuring the annual ring widths along three radii for each disk, averaging these measurements for each disk, and then combining these to represent the average radial growth per tree. Radial increments made from 1935 to 1958 were graphically compared for trees in each competitive situation (figs. 1 to 8). Although these graphical comparisons are case histories of the trees in each competitive situation, they are believed by the author to illustrate the general observed conditions within the study areas.

RESULTS

The damage ratings shown in table 1 and the graphic portrayal of radial and height increment for eight case histories demonstrate that Douglas-fir was not as severely injured by spruce budworm feeding as other host species. Figures 1 to 8 show that radial growth of both Douglas-fir and grand fir declined during the early years of the budworm outbreak but that radial growth of Douglas-fir recovered during the period 1950-55. Figures 1 to 8 show that, in general, height growth of both species declined in 1949; however, height growth of Douglas-fir started an upward trend during 1955-57 but height growth of most grand fir trees continued to decrease. In six of eight competitive situations, grand fir suffered topkilling, three grand firs gradually developed new tops, and on others deterioration of killed tops was progressive.

Differential effects of spruce budworm feeding on these two tree species are thus clearly shown. Whether grand fir is a preferred host, as compared with Douglas-fir, cannot be proven by these data.

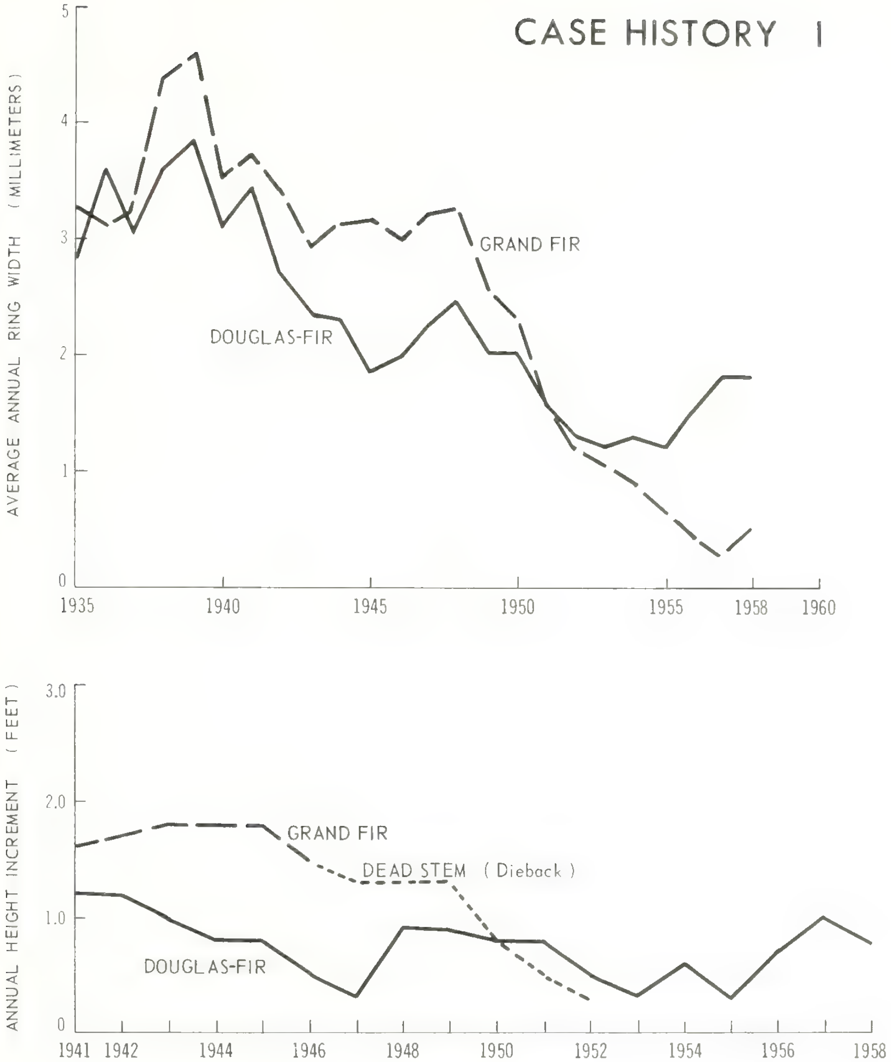
Limited information was also obtained on differential effects of budworm feeding on ponderosa pine (fig. 3) and Engelmann spruce (fig. 5). Generally, the growth rate of spruce was reduced more than either ponderosa pine or Douglas-fir.

Table 1.--Case histories for insect-damaged trees involved in each competitive situation, Wallowa National Forest, 1941-58

Case history	Tree species	Damage class	Damage description	Age[1/]	D.b.h.	Total height		Height when topkilling occurred on grand fir	Length of dead top	Net height growth, 1941-58	Live height, 1958
						1941	1958				
				Years	Inches	----------	----------	----------	Feet	----------	----------
1	Grand fir	III	Heavy	62	9.5	20.3	36.0	36.0	5.2	10.5	30.8
	Douglas-fir	I	Light	71	9.7	29.6	43.0	39.3	0	13.4	43.0
2	Douglas-fir	I	Light	61	9.8	25.3	44.0	40.8	0	18.7	44.0
	Grand fir	II	Moderate	66	8.8	25.5	39.0	39.0	3.8	9.7	35.2
3	Grand fir	III	Heavy	70	8.8	34.7	50.0	50.0	3.6	11.7	46.4
	Douglas-fir	I	Light	71	14.4	37.0	53.0	48.4	0	16.0	53.0
	Ponderosa pine	I	Light	74	13.0	38.6	53.0	50.7	0	14.4	53.0
4	Grand fir	IV	Severe	55	11.1	39.9	50.0	50.0	19.8	0	30.2
	Douglas-fir	I	Light	--	11.3	37.9	55.0	46.9	0	17.1	55.0
5	Grand fir	III	Heavy	112	14.0	71.2	81.0	81.0	14.0	0	67.0
	Engelmann spruce	II	Moderate	135	15.8	80.2	88.0	85.1	0	7.8	88.0
	Douglas-fir	I	Light	140	13.4	72.0	81.0	76.6	0	9.0	81.0
6	Douglas-fir	I	Light	125	10.2	52.2	63.0	59.0	0	10.8	63.0
	Grand fir	IV	Severe	128	12.0	69.4	85.0	80.8	8.4	7.2	76.6
	Grand fir	IV	Severe	110	10.2	59.4	72.0	72.0	5.5	8.3	67.6
7	Douglas-fir	I	Light	68	9.5	27.9	47.0	--	0	19.1	47.0
	Grand fir	I	Light	62	11.1	36.7	57.0	--	0	20.3	57.0
8	Douglas-fir	I	Light	64	10.1	29.4	46.0	--	0	16.6	46.0
	Grand fir	I	Light	65	10.5	40.2	58.0	--	0	17.8	58.0

[1/] Stump level.

CASE HISTORY I



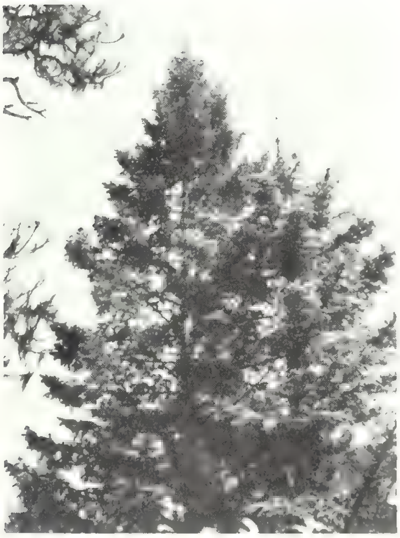


Figure 1.--Annual increment comparisons and photograph of a heavily damaged grand fir and an adjacent, lightly damaged Douglas-fir which appeared to be competing with each other. The grand fir had the higher growth rate and was rapidly overtaking the Douglas-fir until feedings by spruce budworm killed its top and reduced its growth rate more than that of the Douglas-fir.

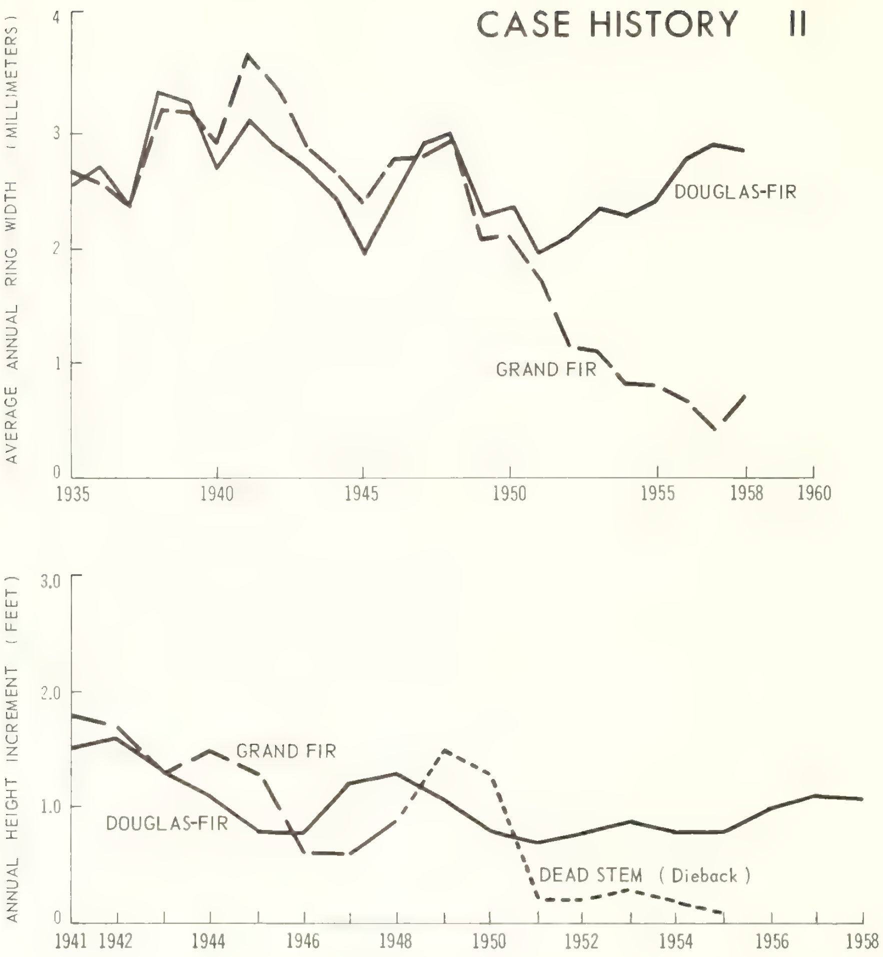
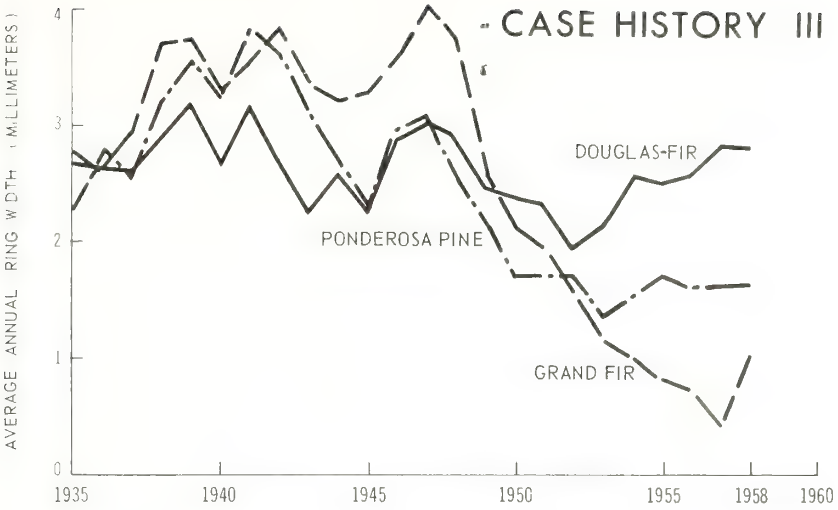
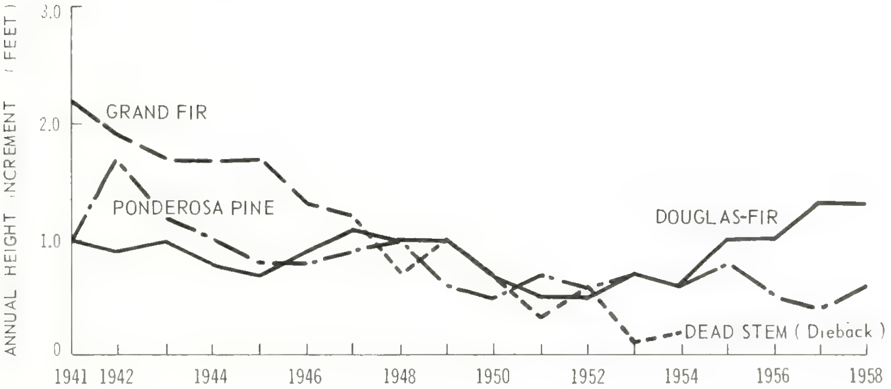


Figure 2.--Annual radial and height growth of a moderately damaged grand fir and an adjacent, lightly damaged Douglas-fir which appeared to be in sharp competition.





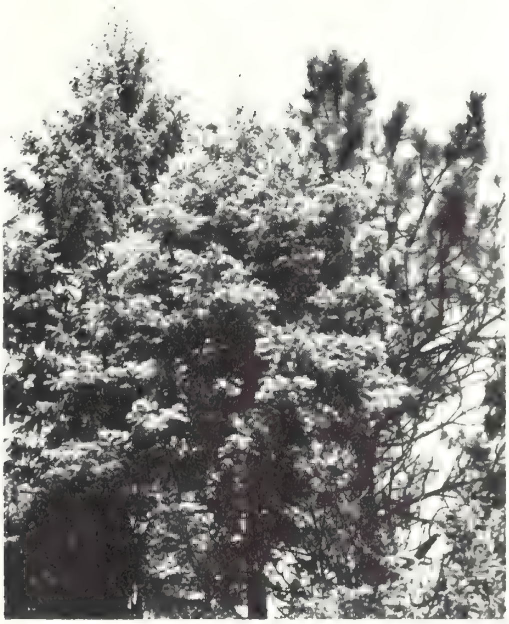
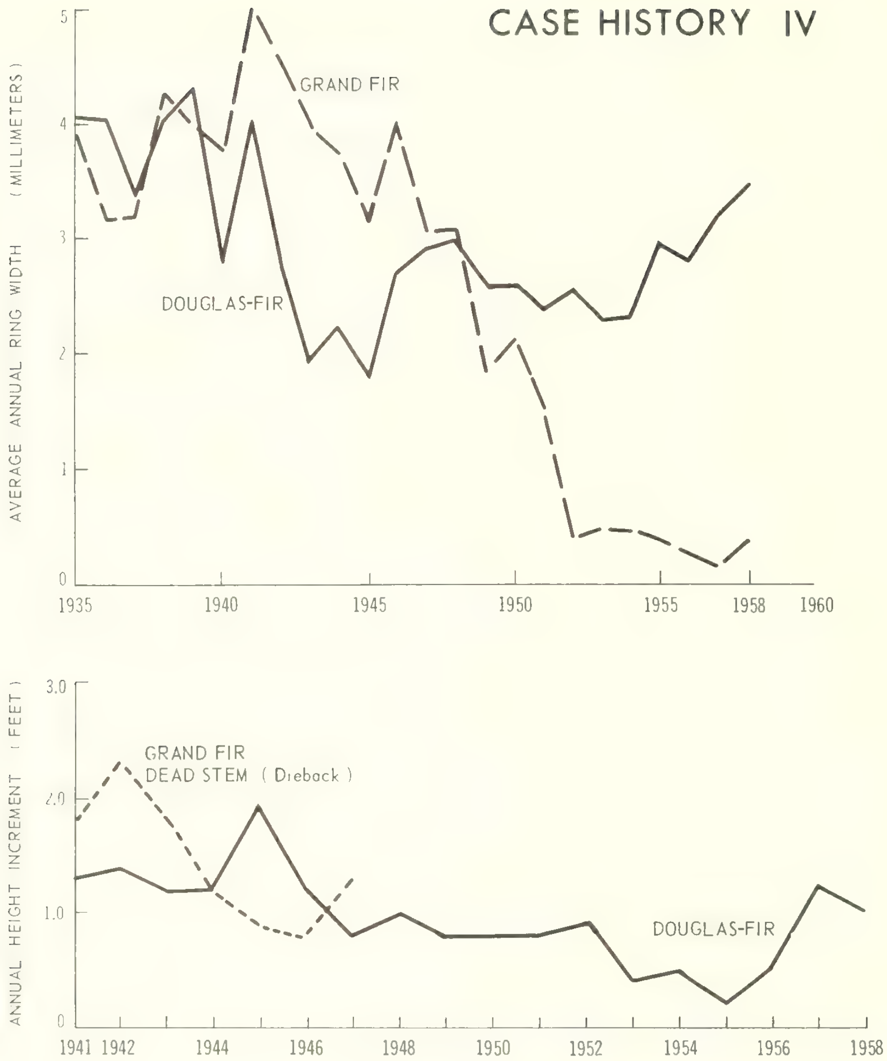


Figure 3.--Annual radial and height growth comparisons and photograph of a heavily damaged grand fir tree and adjacent, lightly damaged Douglas-fir and ponderosa pine trees which appeared in competition for available space, moisture, and nutrients. The grand fir grew more vigorously than its neighbors during the predamage period, but its growth rate was affected most by defoliation. The growth of the pine was intermediately affected, and that of the Douglas-fir least affected by defoliation.

CASE HISTORY IV



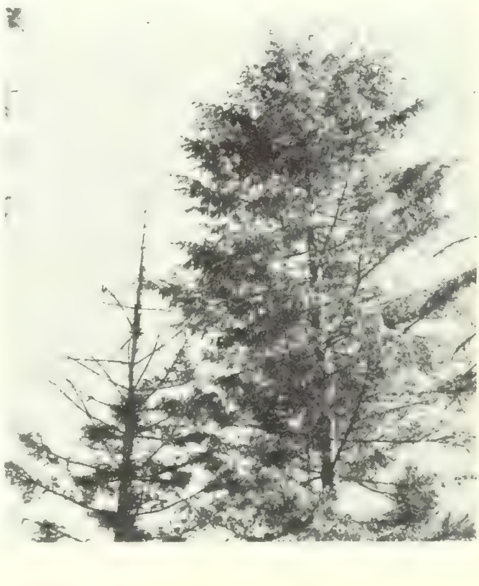


Figure 4.--Annual radial and height increment comparisons and photograph of severely damaged grand fir and adjacent, lightly damaged Douglas-fir trees. These trees appeared to be competing until 1947, when the top of the grand fir was killed by budworm feeding. The following year, the grand fir's radial increment was less than that of the Douglas-fir and remained at a very low level. In the summer of 1958, when the photograph was taken, the once very vigorous grand fir was dying.

CASE HISTORY V

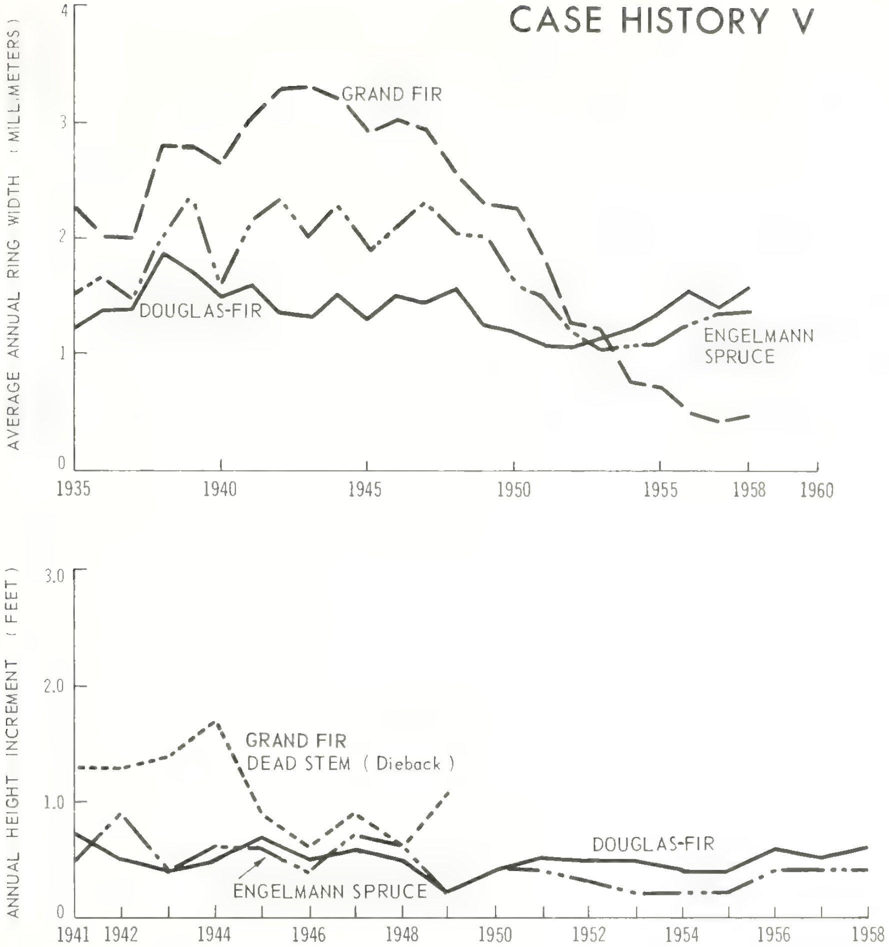


Figure 5.--Average annual height and radial increment comparisons of adjacent heavily damaged grand fir, a moderately damaged Engelmann spruce, and a lightly damaged Douglas-fir tree.

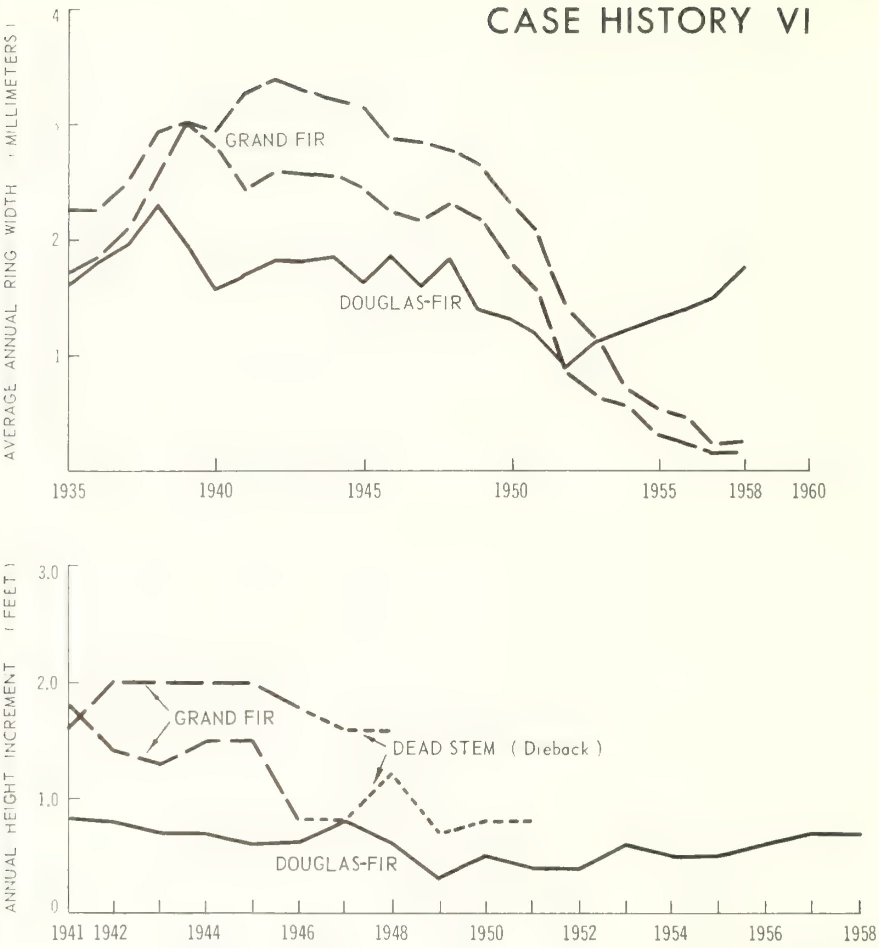
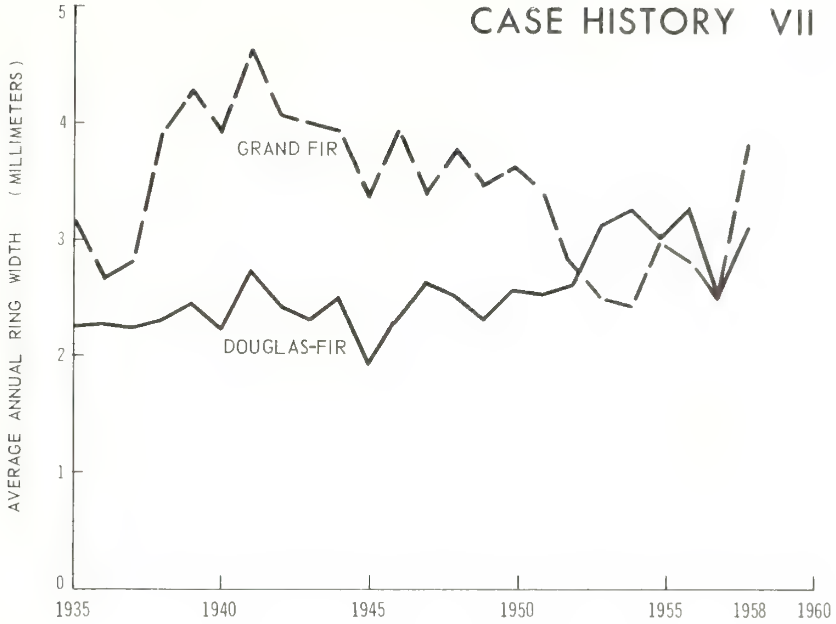
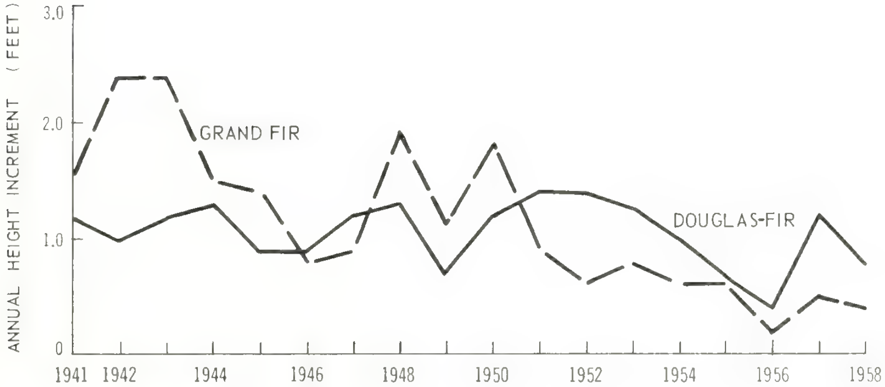


Figure 6.--Annual radial and height growth comparisons of two severely damaged grand fir trees and an adjacent, lightly damaged Douglas-fir tree which appeared to be in competition.

CASE HISTORY VII





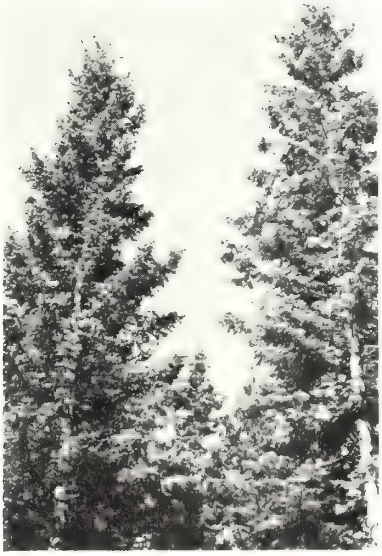


Figure 7.--Annual radial and height increment comparisons and photograph of lightly damaged grand fir and adjacent Douglas-fir trees which appeared in competition. The grand fir grew faster until defoliation reduced its rate of increment below that of the Douglas-fir. In 1958, the radial increment of the grand fir again surpassed that of the Douglas-fir, although height growth still lagged.

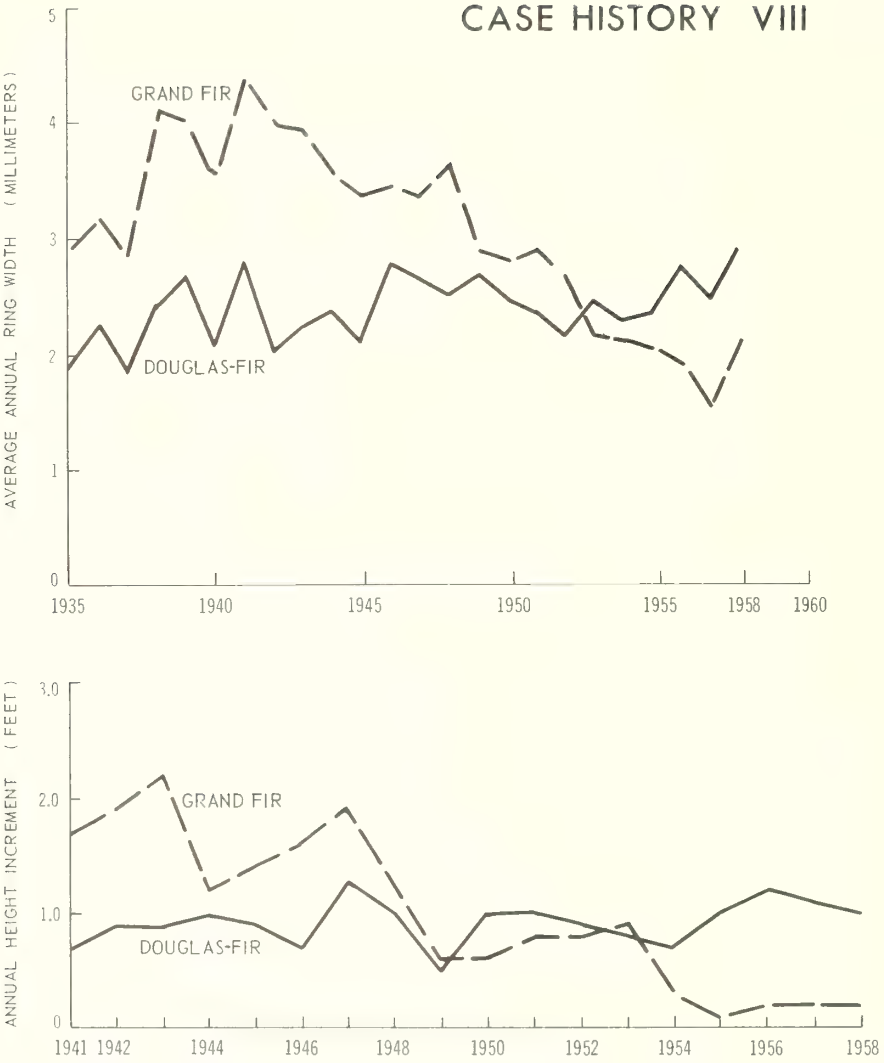


Figure 8.--Annual radial and height increment comparisons between lightly damaged Douglas-fir and adjacent grand fir trees which appeared to be in competition.

DISCUSSION

Effect of Defoliation on Host Species Competition

On the study areas, damage from defoliation by the spruce budworm was most severe and most variable on grand fir, intermediate on Engelmann spruce, and least on Douglas-fir and ponderosa pine. Grand fir was the fastest growing tree in each competitive situation prior to the budworm outbreak and was consistently damaged more than other competing species. This indicates that budworm feeding populations may be greater on grand fir than on other species and/or similar populations may do more damage to grand fir.

A study made in eastern Oregon by the U.S. Forest Service (1960) showed that similar larval populations caused heavier defoliation and greater budkilling on white (grand) fir than on Douglas-fir. Also, larval survival was found to be higher on white fir than on Douglas-fir. Thus, grand fir is not only more susceptible but also appears to provide more food and/or protection for budworm larvae.

One of the reasons for drastic reduction in the competitive position of grand fir was the high incidence of topkilling that occurred within the species as a result of defoliation. A possible explanation for this is differences in vertical distribution of budworm populations between tree species. In eastern Oregon, median budworm populations were found in the middle third of the crown of grand fir, as in Douglas-fir; however, compared with Douglas-fir, egg masses were more numerous in the upper crown of grand firs and less numerous in the lower crowns (U.S. Forest Service 1961). High populations in the area of the crown, which contained the smallest vegetative bud and foliage complements, logically would be important. This difference in vertical distribution of budworm population occurred between species during the time (1959-60) when populations were low. It appears that a high degree of damage in the upper areas of crowns will result when populations increase and the amount of available food is drastically reduced.

The importance of this difference between tree species in budworm population distribution among crown thirds is accentuated when one realizes that the smaller foliage complement of the upper crown contains a high proportion of the current year's leaves. Since this age group is consumed by budworm larvae before other age groups, the difference in population distribution may explain the heavy top defoliation and topkilling exhibited by many grand fir trees in the areas studied.

Engelmann spruce exhibited the second widest damage variations in the areas studied. In general, these trees were much older, larger, and slower growing than the other species. Their recovery was slower. Ponderosa pine exhibited few external signs of damage and its growth rate was only slightly reduced.

Douglas-fir increment was adversely affected by budworm defoliation, but never to the extent of the associated species. Thus, its relative competitive position was improved. In many cases, Douglas-fir increment increased after initially declining in response to defoliation; on adjacent grand fir or Engelmann spruce, growth continued to decline.

Douglas-fir trees may have the ability to sustain heavy defoliation and remain alive. Silver (1960), describing an outbreak by the spruce budworm in British Columbia, reported that numerous trees had all buds killed and lost over 90 percent of their foliage. However, no tree mortality occurred. Topkilling was common but usually affected only a few years of terminal growth. However, the outbreak lasted only 6 years, and no locality was subjected to more than 2 years of continuous severe defoliation.

The author has observed young shoots on Douglas-firs still elongating several weeks after the completion of budworm larval development. The new leaves produced on these elongating shoots escape injury by spruce budworm larvae for the season. Consequently, Douglas-fir would be affected less by spruce budworm defoliation than the true firs whose seasonal shoot elongation is completed earlier.

Understory in most stands damaged by defoliation was predominantly grand fir. In several locations, many of these young trees were almost stripped of foliage, and in others they appeared to be hardly touched by the spruce budworm. After the budworm outbreak subsided, many of these trees recovered rapidly from the effects of defoliation and in a few years regained favorable competitive positions relative to adjacent associate species (fig. 9). Many grand fir laterals, which had turned up to become leaders, exhibited vigorous height growth, often exceeding the normal leader height growth of less budworm-susceptible species.

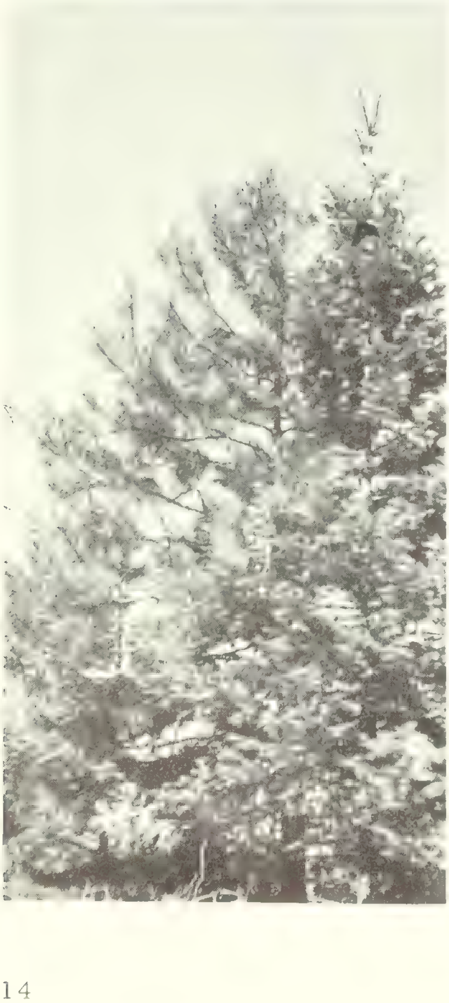


Figure 9.--A young grand fir adjacent to a young ponderosa pine. The grand fir's top was killed during the damage period, but after the budworm outbreak subsided, two new leaders were formed and grew vigorously, quickly overtopping the adjacent pine.

Epidemiology

The susceptibility of grand fir to budworm defoliation suggests that the species may be analogous to balsam fir (*Abies balsamea* (L.) Mill.) of Eastern North America in this respect. In the East, spruce budworm outbreaks develop and gain momentum in forests characterized by a high content of mature or overmature balsam fir spread over large areas (Morris 1958). Increases in budworm populations seem to favor balsam as contrasted to spruce (usually white spruce, *Picea glauca* (Moench) Voss), mature balsam as contrasted to young age classes, dense stocking of balsam as contrasted to open stocking, and extensive areas of balsam as contrasted to isolated stands (Morris 1958).

One thing the study areas in the Wallowa National Forest had in common was a substantial number of grand fir trees. Other areas in eastern Oregon, shown by aerial damage survey maps to have experienced severe defoliation damage, also had grand fir. An examination of the budworm dynamics from 1947 to 1958, mapped by annual aerial surveys, revealed that these areas were the focal points from which the budworm outbreaks spread and to which they eventually withdrew.

The reasons for the relative success of budworm populations on mature and overmature balsam fir appear to be nutritional and phenological. Budworm survival and development are high in balsam fir staminate cones, and mature flowering trees contain heavier budworm populations than nonflowering trees (Blais 1952). Mature flowering trees are usually the dominant ones in the stand, and they are the ones preferred by ovipositing females (Morris 1955). Overwintering budworm larvae emerge contemporaneously with the expansion of balsam fir vegetative buds and are provided with suitable food at the right time (Graham 1952, *p. 201*).

A study of spruce budworm development under field conditions in eastern Oregon reported that budworm larval growth and development was related to the growth of grand fir (Wagg 1958). If the growth variation between trees in dense stands and those in open stands was considered, it was possible to estimate budworm larval development from the amount of grand fir lateral stem growth. This suggests that budworm development in the Pacific Northwest is related to the development of the current year's grand fir foliage--a phenological event analogous to that of balsam fir and the budworm in the Northeastern States.

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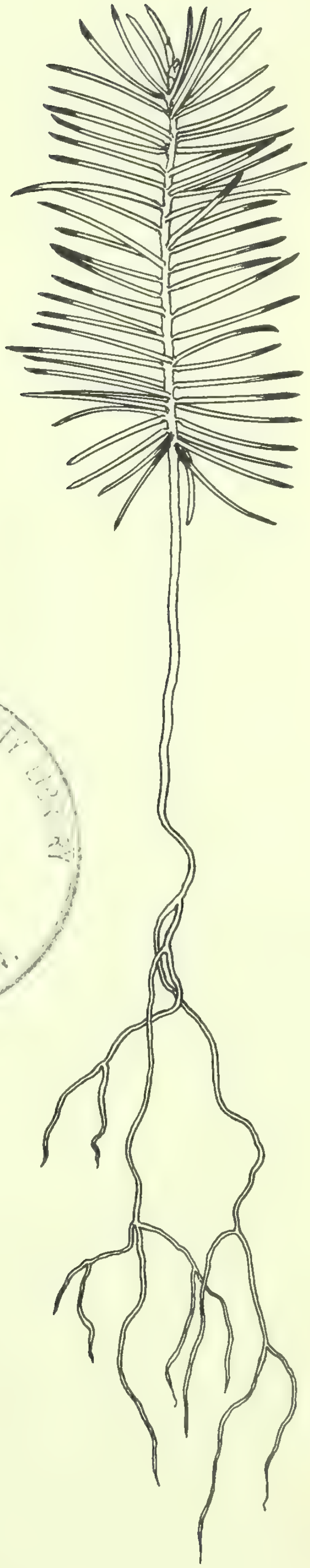
Absorption and Distribution of C^{14}-labeled TETRAMINE in relation to its possible use in ANIMAL DAMAGE CONTROL



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RESEARCH PAPER PNW 34
JULY 1966

INTRODUCTION

Tetramethylenedisulphotetramine (tetramine) is an extremely toxic chemical (Hagen 1950).[1] Shortly after its discovery in Germany (Hecht and Henecka 1949), it was introduced in the United States and found useful as an experimental seed protectant in reforestation by direct seeding (Spencer 1954).

The first indication of tetramine's systemic characteristics was that seedlings grown from tetramine-treated seed were toxic to rodents during the first month after germination (Spencer 1954). This observation led to (1) bioassay studies to determine translocation of the chemical and (2) pen and field tests to evaluate the effectiveness of tetramine as a systemic chemical for protecting seedlings against wild animals (Kverno 1960). In order to more fully evaluate the potential usefulness of tetramine for practical application, additional studies were undertaken of the chemical's translocation patterns in plants and its fate in plants and animals.[2] This paper, one of several reports on these studies, describes the patterns of absorption, translocation, and mobility of tetramine in three plant species.

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[1] Names and dates in parentheses refer to Literature Cited, p. 16.

[2] All work with animals is in cooperation with the Olympia Field Station of the U. S. Bureau of Sport Fisheries and Wildlife, Olympia, Wash.

MATERIALS AND METHODS

Douglas-fir *(Pseudotsuga menziesii* (Mirb.) Franco), blackberry *(Rubus ursinus* Cham. & Schlecht.), and orchard grass *(Dactylis glomerata* L.) served as experimental material. These plants, respectively, were used to represent gymnosperms, dicotyledonous angiosperms, and monocotlyedonous angiosperms. One seed lot of low-elevation Douglas-fir, one lot of orchard grass seed, and cuttings from one blackberry plant were used to grow plants needed for all experiments.

CULTURE OF PLANTS

Young plants of the three species were grown in sand until they reached a height of 3 to 5 inches. Plants were then washed free of sand, selected for uniform height, transferred to quart Mason jars covered with aluminum foil and containing Hoagland's nutrient solution 1 (Hoagland and Arnon 1950) with three parts per million (p.p.m.) of chelated iron, and placed in a plant growth chamber. Temperatures in the chamber were 26° C. during the day and 16° C. at night. Root zone temperature remained constant at 19° C. Relative humidity ranged from 70 to 90 percent, and light (at level of plant leaves) was controlled at 1,800 foot-candles on a 14-hour photoperiod. Culture solutions were continuously aerated, and plants were allowed to acclimatize in the chamber for at least 10 days before treatment.

TREATMENT OF PLANTS

C^{14}-labeled tetramine with a specific activity of 2.02 millicuries per millimole was prepared by Tracerlab, Waltham, Massachusetts. Stock solutions of the chemical were freshly prepared for the different experiments. Solutions for root and foliar treatments, respectively, were 20 p.p.m. in 1-percent acetone solution and 1,000 p.p.m. in 80-percent acetone solution containing 0.1-percent "Tween 20" surfactant.

Four tests were made with the tracer to determine (1) uptake by roots and distribution in the shoots, (2) mobility within treated plants, (3) distribution to flowering parts (blackberry only), and (4) movement following foliar applications.

UPTAKE BY ROOTS AND PROGRESSIVE DISTRIBUTION

Roots of grass, blackberry, and Douglas-fir plants were subjected to C^{14}-labeled tetramine (tetramine*) for 2, 6, 8, 24, and 96 hours. Tetramine* was used at the rate of 100 milliliters of stock solution (root treatment solution) to 700 milliliters of nutrient solution to form treatment solutions of 800 milliliters, each containing 2.0 milligrams tetramine* (17 microcuries). Four plants of each species, paired in two jars, were used per treatment. In each case, plants were transferred to treatment solutions and resulting cultures were moved immediately to the growth chamber. Growth conditions were the same as previously outlined and solutions were continuously aerated during the experiment. At the end of each exposure period in the time series, plants were removed from treatment solutions and processed as later described.

MOBILITY WITHIN PLANTS

Eight plants of each species were root treated with tetramine* as outlined above. Grass and blackberry were treated for 6 hours; Douglas-fir seedlings were treated for 48 hours. After treatment, roots were washed in distilled water and plants were transferred to tetramine-free nutrient solutions. Cultures were returned to the growth chamber and allowed to grow under the usual conditions. Solutions were changed every 2 days the first week and once a week thereafter. Four plants each of grass, blackberry, and Douglas-fir were harvested after 7, 7, and 30 days, respectively. Remaining grass and blackberry were allowed to grow for an additional 7 days; Douglas-fir was grown for another 30 days before the experiment was terminated.

DISTRIBUTION IN FLOWERING PLANTS

Four blackberry plants with flower buds were treated for 48 hours with tetramine* via the roots as previously described. Roots were then washed in distilled water and the plants transferred to tetramine-free nutrient solutions. Cultures were returned immediately to the growth chamber, and solutions were changed every 2 days. Plants were harvested when most flowers had opened.

MOVEMENT AFTER FOLIAR APPLICATION

Four plants of each of the three species were used. Tetramine* was applied at the rate of 50 microliters of stock solution (foliar treatment solution) containing 50 micrograms tetramine* (0.42 microcurie) per plant. Solution was applied with a micropipette to one mature leaf of each grass and blackberry and to a group of mature needles of each Douglas-fir. Treatment was for 7 days under growth chamber conditions outlined above.

PROCESSING OF HARVESTED PLANTS

At time of harvest indicated for each experiment, roots of treated plants were washed thoroughly in distilled water and blotted with soft tissue. Treated leaves (from foliar application) were partly covered with masking tape to prevent contamination during further processing. Intact plants were then quick-frozen with crushed solid carbon dioxide and freeze-dried immediately at −15° C. (Pallas and Crafts 1957).

ASSAY METHODS

The autoradiographic method (Yamaguchi and Crafts 1958) was used to determine distribution of C^{14} in treated plants. For each treatment, the best two plants were mounted on paper and placed against no-screen X-ray film for 4 weeks at room temperature. After exposure, films were developed by standard procedure to produce photographic images resulting from tracer radioactivity. The dark areas on resulting autoradiograms were used to determine location of the tracer in treated plants.

RESULTS AND DISCUSSION

Results of the different treatments are presented in the form of autoradiograms of representative plants.

Although the autoradiographic method has some limitations, in this study the method proved satisfactory. Control plants of the three species produced no pseudoautoradiograms, agreement among replications was good, and levels of activity employed were well within the limits of resolution of the X-ray film.

In presentation and discussion of results, C^{14} in the plants is, for simplicity, often referred to as tetramine*. Whether activity in the tissues was due to tetramine* or to a metabolite thereof is currently being investigated.

UPTAKE BY ROOTS AND PROGRESSIVE DISTRIBUTION

Autoradiograms and mounted plants of grass, blackberry, and Douglas-fir, representing progressive absorption and upward movement of tetramine* from root treatments of 2 to 96 hours, are shown in figures 1A to 1E. An examination of these autoradiograms shows that much higher concentrations of labeled material from nutrient solutions were retained in roots of the three species than were moved into the tops. This difference suggests that roots of the test species may fix, metabolize, or metabolically absorb tetramine*.

Differences between species in rates of translocation of the labeled material are also evident. In 2 hours (fig. 1A), Douglas-fir translocated almost no tracer to aerial parts; blackberry translocated enough so that the shoot image was very slightly visible; and grass moved sufficient material to the leaves to give a clearly visible autoradiogram of the whole plant. Only after 24 hours (fig. 1D) did activity become visible in tops of Douglas-fir. The slow movement in Douglas-fir was probably due to its characteristic meager root absorbing area, smaller area of transpiring foliage, and lack of vessels compared with the other species. These characteristics probably restricted uptake and transport in the xylem.

As absorption and translocation continued, the tracer accumulated in older parts of leaves where transpiration presumably occurred most rapidly. This pattern is clearly displayed in figures 1C and 1D in tips of grass leaves and in figure 3 at leaf margins of blackberry.

During the entire experiment, absorption of tetramine* continued, as evidenced by the sequence of autoradiograms in figure 1. Also, individual treatments showed presence of high activity in older leaves only, suggesting that the tracer was carried upward in the transpiration stream and retranslocation out of older leaves probably did not occur.

MOBILITY WITHIN PLANTS

Lack of mobility of tetramine* within plants is shown in figures 2 to 4. Initially (figs. 2A to 4A), slight movement into new growth (leaves without arrows in figure 2 and growth above the arrows in figures 3 and 4) occurred after removal of plants from treatment solutions. This movement probably was not derived from old growth (tops present at time of treatment). More likely, tracer moved into new growth from excess tracer in or on the washed roots.

As growth continued in tetramine-free solutions, old roots showed less tracer as they elongated and new roots contained little or no activity (figs. 2B to 4B). Similarly, little or no tracer was present in new aerial parts. In the meantime, old shoots and roots showed slight loss of activity, which was probably due to dilution by tissue growth or by degradation of tetramine*.

Tetramine*, therefore, was markedly immobile (nonsystemic) in the three species. Once deposited, it did not recirculate readily within the plant.

DISTRIBUTION IN FLOWERING PLANTS

Autoradiograms in figures 5A and 5B show appreciable activity in open flowers of blackberry plants which were treated after flowers had formed. The tracer was present in all flower parts, especially the calyx. Much less activity, however, appeared in the cluster of flower buds shown in figure 3B and marked by "X" where flowers were initiated after treatment and during growth in tetramine-free solution.

Apparently, tetramine* must be available to the roots during flowering for the tracer to appear in appreciable amounts in the flowers. Activity acquired before flowering is not readily available for redistribution and deposition in new flowers because of the chemical's marked immobility, as indicated in the mobility experiment above.

MOVEMENT AFTER FOLIAR APPLICATION

Areas of leaves and needles where the acetone solution was applied did not show any sign of damage to the tissues. The autoradiograms (fig. 6) show that movement out of treated leaves was, at best, very limited. Most noticeable movement occurred in grass (fig. 6A) where the tracer moved from point of application toward the tip of the treated leaf. Similar slight movement probably occurred in blackberry and Douglas-fir. Clear detection of the tracer on the autoradiograms (figs. 6B and 6C), however, was not possible because of shorter leaves of the species and the tape covering treatment areas. Figure 6 also shows no basipetal movement of tracer in any of the three species.

Movement of tracer toward tips of treated leaves in direction of the transpiration stream and not in direction of assimilate movement presents additional evidence (see above) of relative immobility of tetramine* in the plant. Applications of tetramine* to tops of plants, therefore, would not result in movement to roots.

SUMMARY AND CONCLUSIONS

Absorption, translocation, and mobility of C^{14}-labeled tetramine were studied in orchard grass, blackberry, and Douglas-fir plants. Tagged tetramine was applied to the roots in nutrient solutions and to the foliage, and the autoradiographic method was employed to determine distribution of the tracer.

Tetramine* was absorbed from nutrient solution by roots of the three species. Transport occurred via the transpiration stream and was apparently dependent on area of transpiring foliage and extent of absorbing root system. Thus, upward movement was slowest in Douglas-fir and fastest in orchard grass.

After uptake by roots and deposition in plant tissues, tetramine* did not recirculate within the plant in any of the species. Immobility of the chemical was also demonstrated by lack of downward movement with the assimilate stream after foliar applications to mature leaves. Tetramine, therefore, did not behave as a systemic chemical in the test species.

Appreciable amounts of tetramine* appeared in blackberry flowers when plants were treated after flower initiation had begun, but the chemical did not move to flowers formed after treatment had ceased.

In addition to tetramine's known toxicity, results point to serious limitations to its use to protect Douglas-fir seedlings from animals. If tetramine is applied to Douglas-fir in the nursery before outplanting, protection would last through the first dormant season only. New growth would not be protected because of the chemical's immobility (nonsystemic properties). In this case, field applications would be necessary to protect new growth. On the other hand, if tetramine is applied in the field, the chemical becomes available to other plant species associating with Douglas-fir (e.g., grass and blackberry). Foliage and fruit of these plants may become as toxic — or perhaps more so — as the trees, presenting an additional hazard to man, livestock, and wild animals unless tetramine is metabolized into a safer compound.

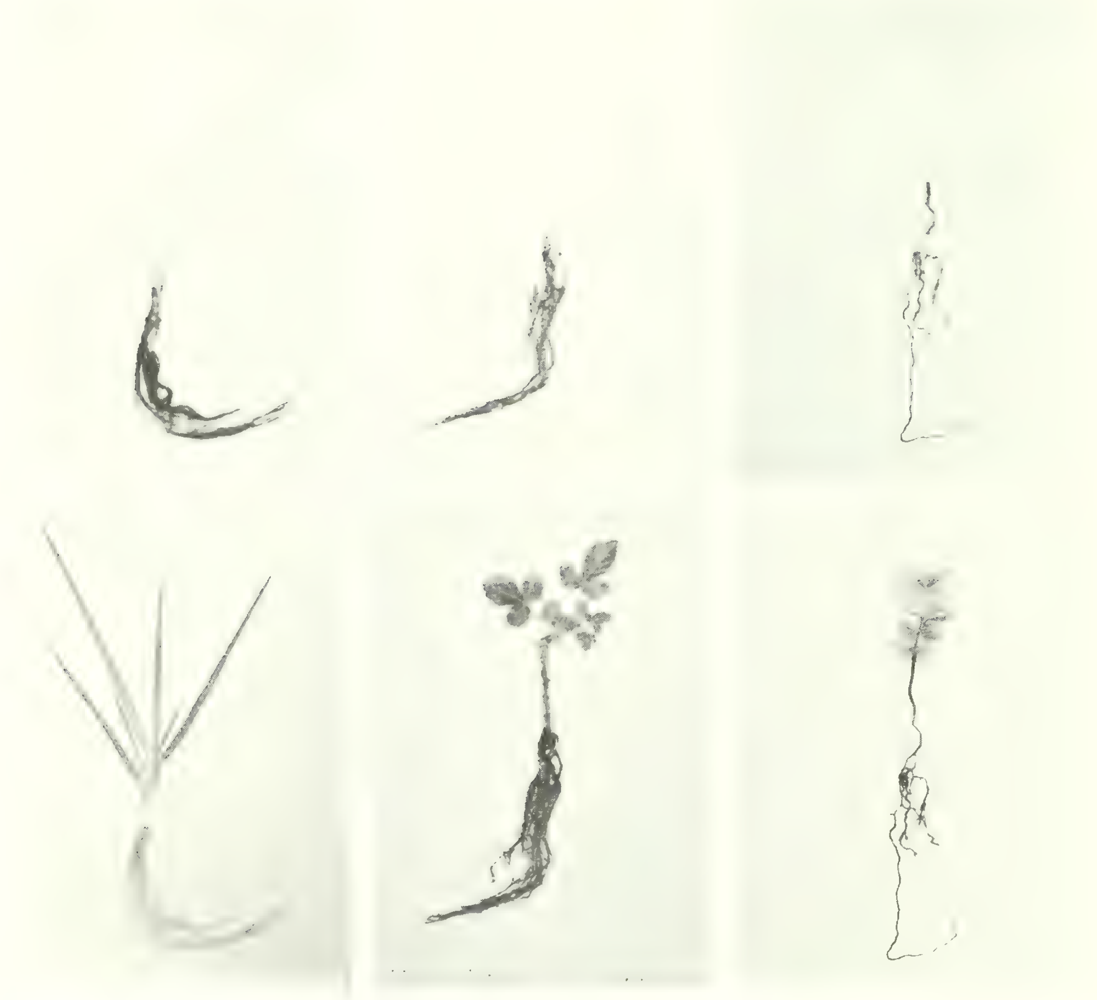


FIGURE 1A. TREATMENT PERIOD: 2 HOURS

Comparative uptake and upward movement of tetramine-C^{14} in grass, blackberry, and Douglas-fir through a 96-hour period. Tetramine was administered via the culture solution at 2.5 p.p.m. for several treatment periods. Autoradiograms appear above the mounted plants.

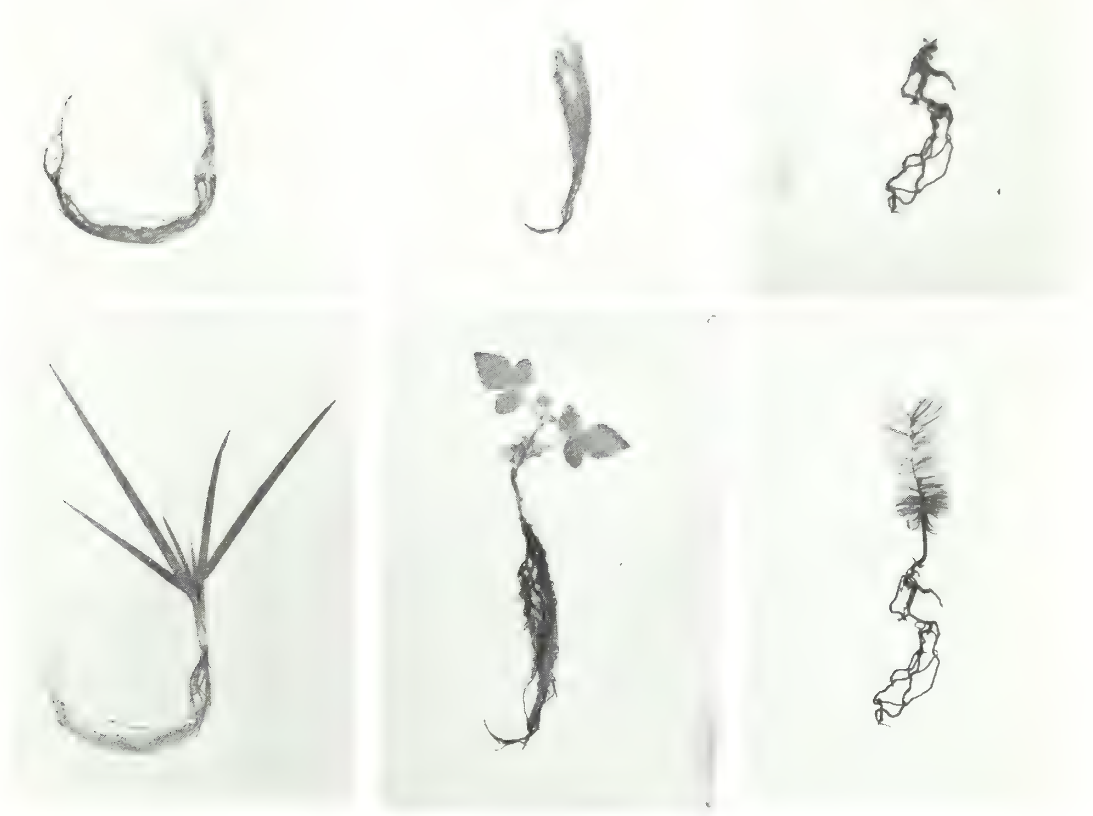


FIGURE 1B. TREATMENT PERIOD: 6 HOURS

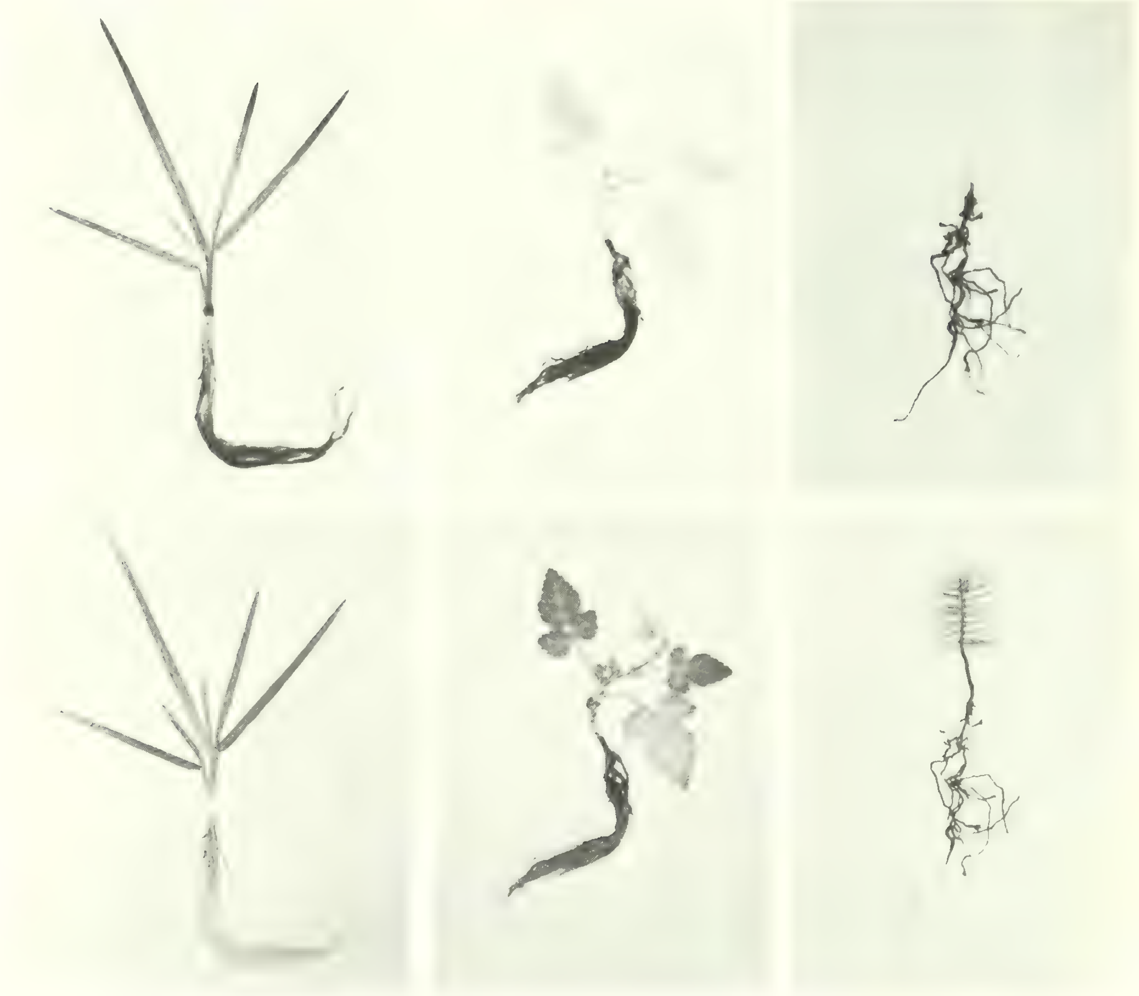


FIGURE 1C. TREATMENT PERIOD: 8 HOURS

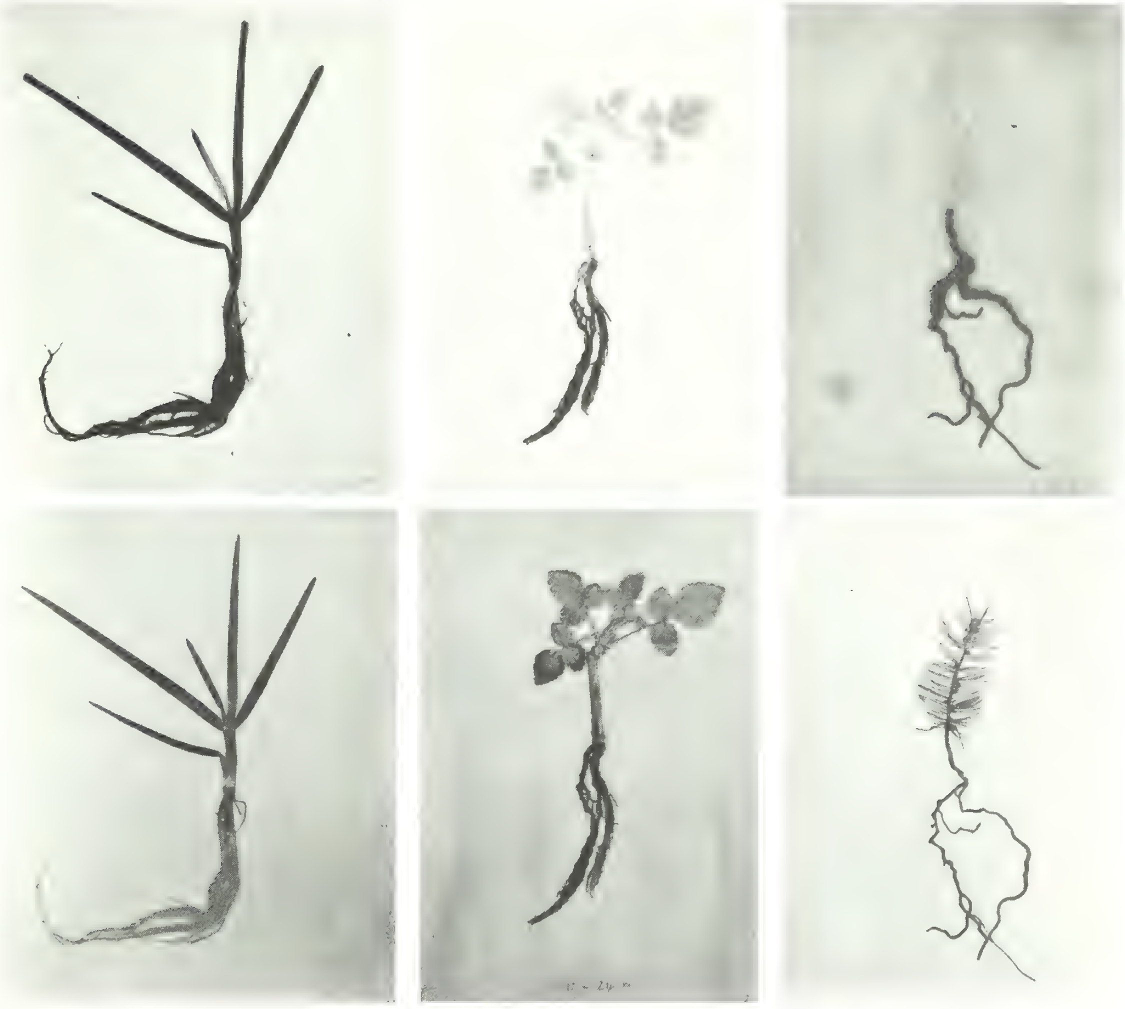


FIGURE 1D. TREATMENT PERIOD: 24 HOURS

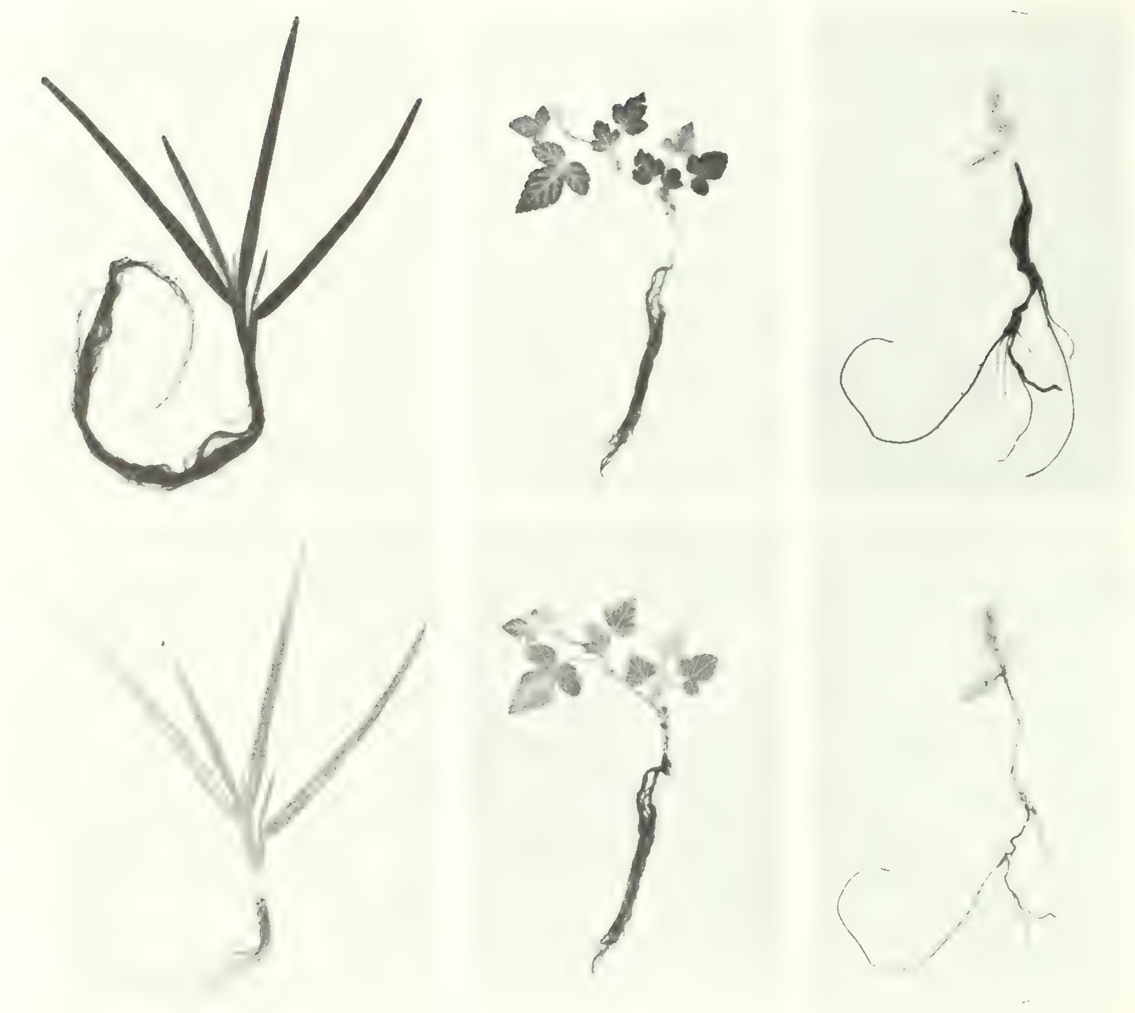
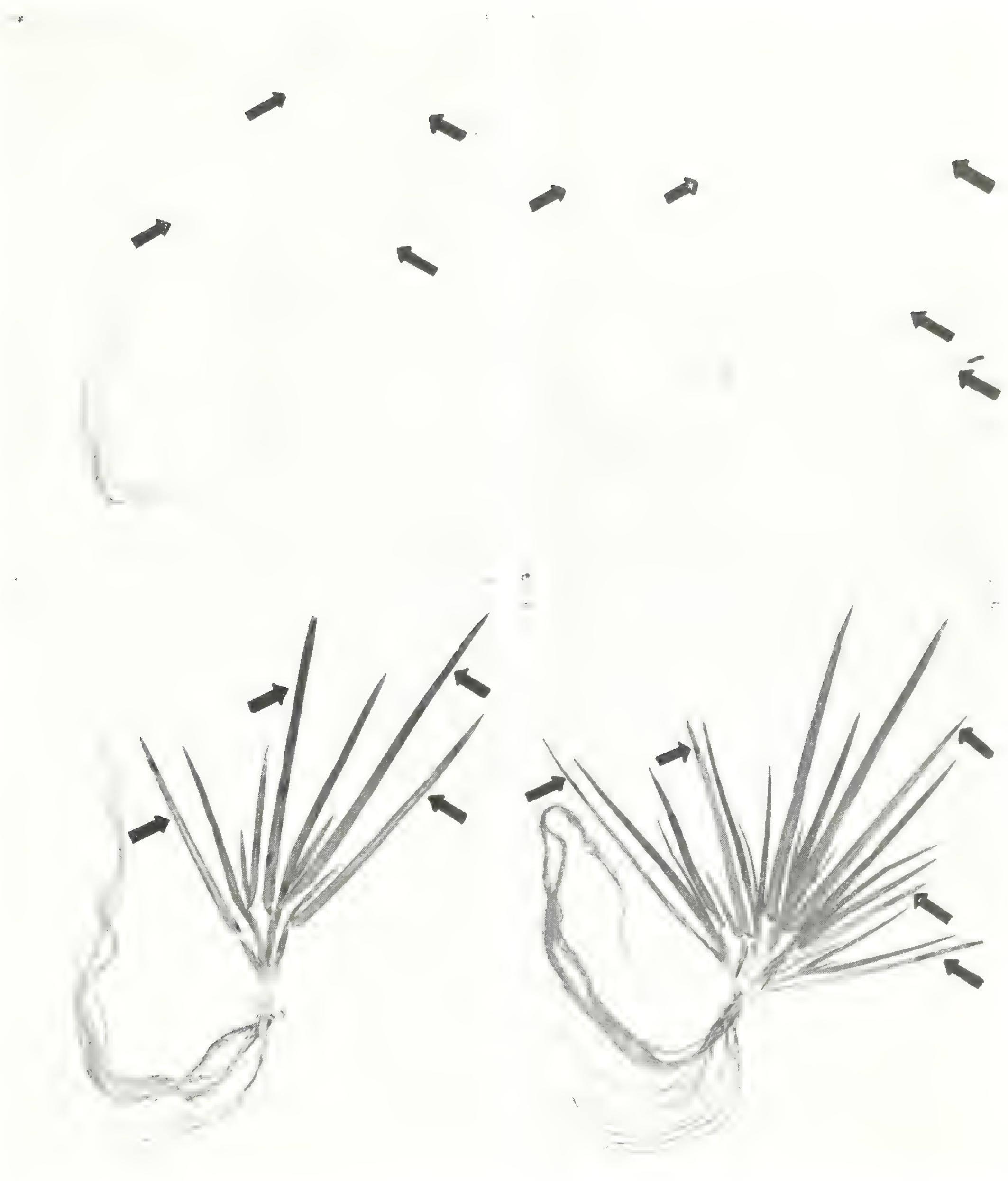
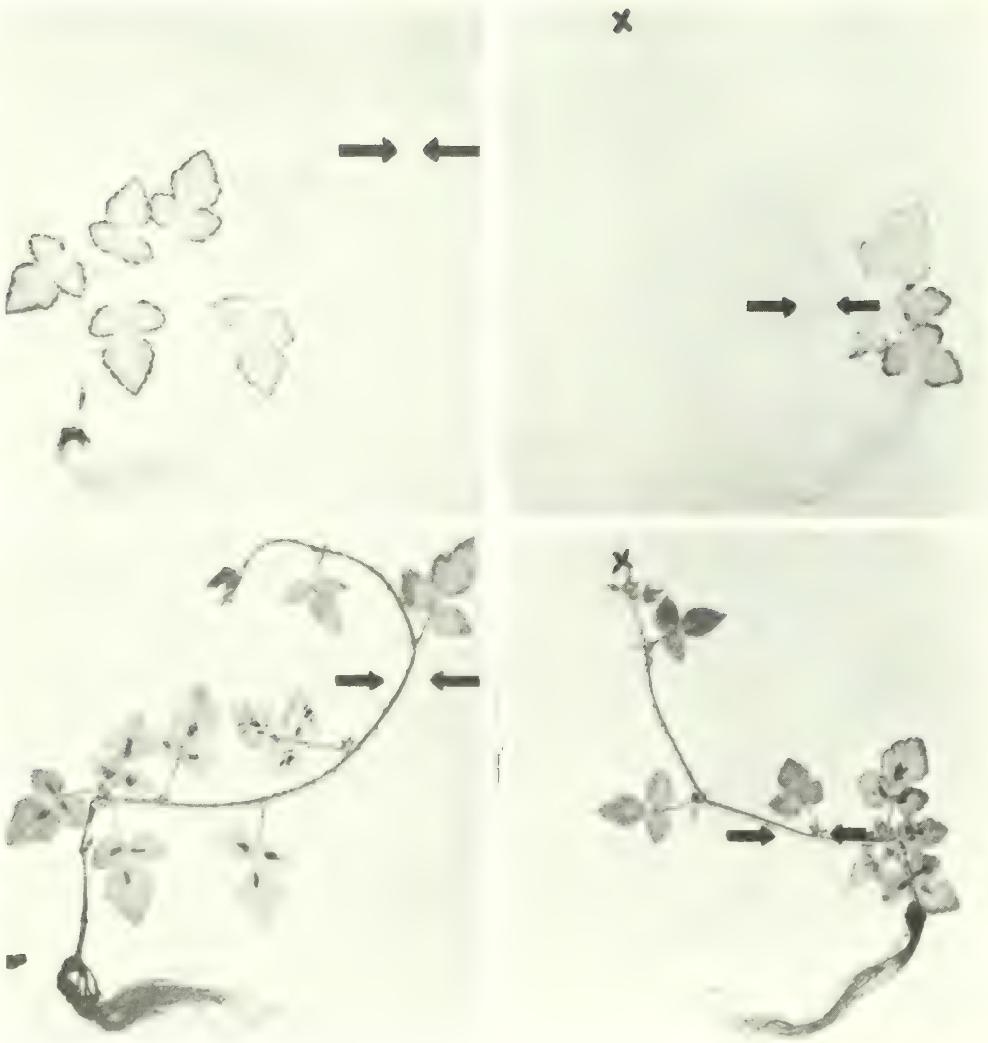


FIGURE 1E. TREATMENT PERIOD: 96 HOURS



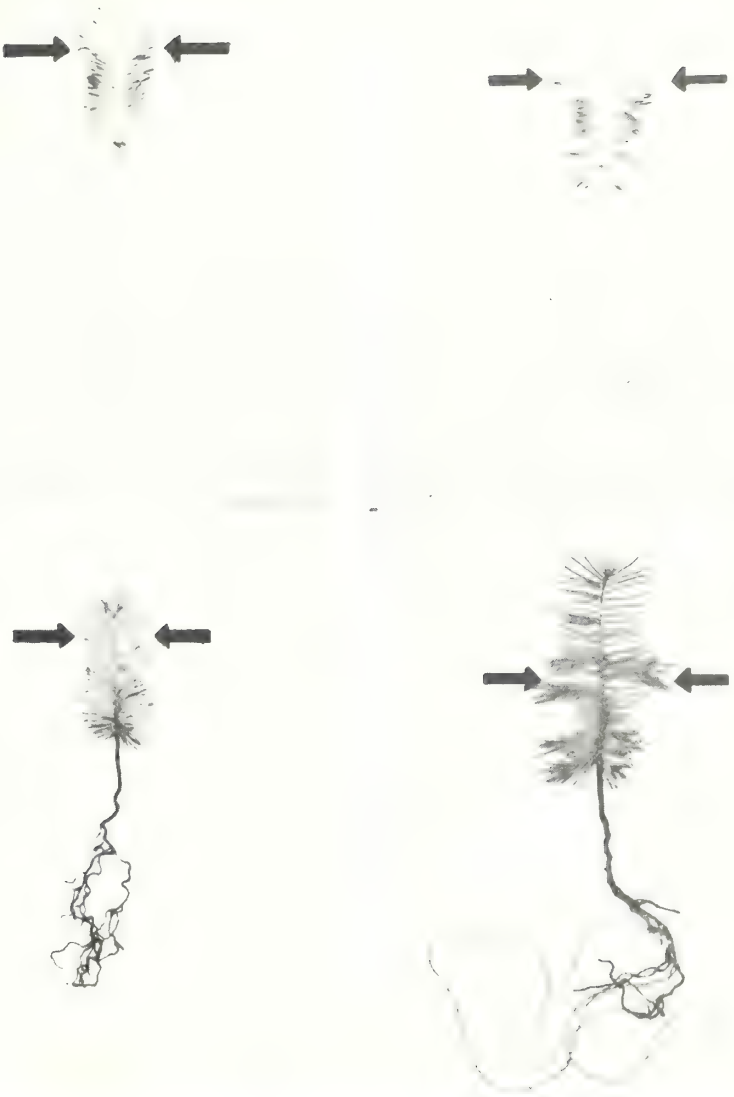
A. 7 DAYS' GROWTH B. 14 DAYS' GROWTH

FIGURE 2. Redistribution of tetramine-C^{14} in grass. Seedlings were treated for 6 hours with tetramine-C^{14} in culture solution at 2.5 p.p.m. before they were transferred to tetramine-free solution and allowed to grow. Upper section shows autoradiograms of treated seedlings shown in lower section, and arrows point to leaves present at time of treatment.



A. 7 DAYS' GROWTH — B. 14 DAYS' GROWTH

FIGURE 3. Redistribution of tetramine-C^{14} in blackberry. A and B treatments are as in figure 2, and autoradiograms are shown above treated plants. Arrows point to position of apical bud at time of treatment and X indicates flower buds in B.



A. 2-DAY TREATMENT
30 DAYS' GROWTH IN
TETRAMINE-FREE SOLUTION

B. 2-DAY TREATMENT
60 DAYS' GROWTH IN
TETRAMINE-FREE SOLUTION

FIGURE 4. Redistribution of tetramine-C^{14} in Douglas-fir. A and B are as in figure 2, except for treatments of 2 days and post-treatments in tetramine-free solutions of 30 days (A) and 60 days (B). Autoradiograms are shown above treated plants, and arrows point to position of apical bud at time of treatment.

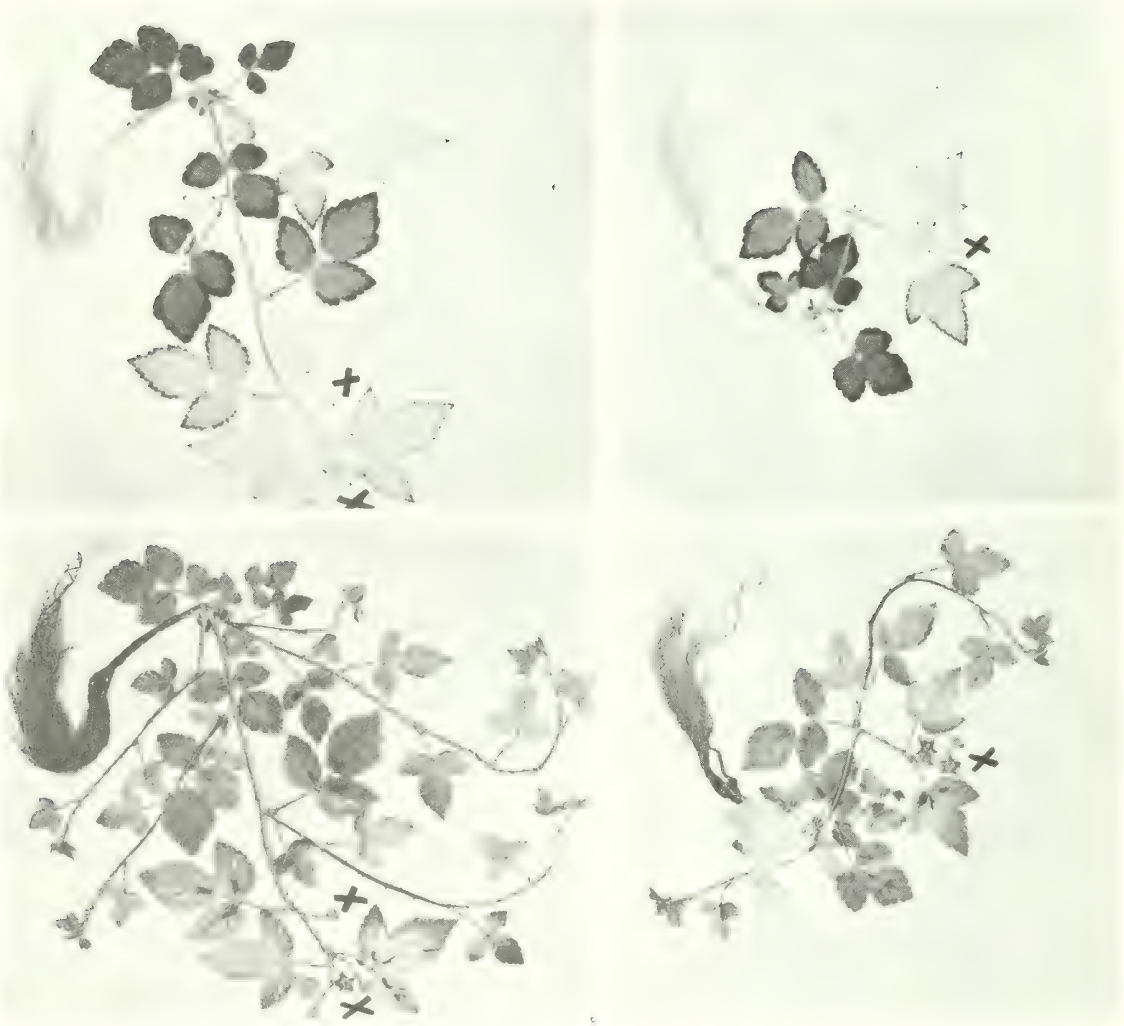
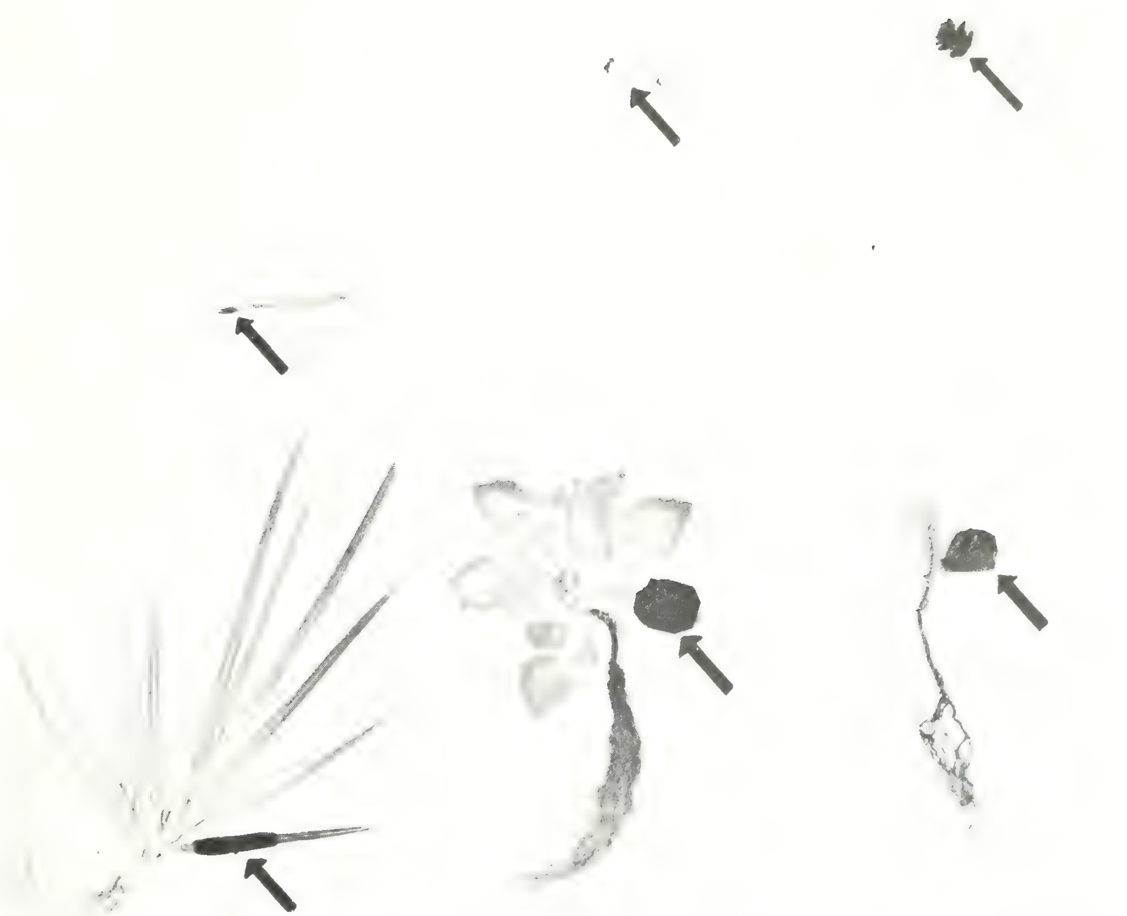


FIGURE 5. Distribution of tetramine-C^{14} in flowering blackberry. Plants with flower buds were treated with tetramine-C^{14} for 48 hours as in figure 2, and then allowed to grow in tetramine-free solution until flowers were fully developed. Autoradiograms are shown above and treated plants below; X indicates position of flowers.



LEAVES OF GRASS BLACKBERRY DOUGLAS-FIR

FIGURE 6. Comparative movement of tetramine-C^{14} from leaves of grass, blackberry, and Douglas-fir. Leaves indicated by arrows were treated for 7 days with 50 micrograms tetramine-C^{14} in 50 microliters of acetone solution. Upper section shows autoradiograms of treated plants shown in lower section.

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